THE SYDNEY HARBOUR BRIDGE

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No. 1.

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THE SYDNEY HARBOUR BRIDGE.

Historical.

Ladies and Gentlemen:

"There is a divinity which shapes our ends,
Rough hew them as we may,"

and when I, as a boy, born at Rainbow Street, Sandgate, Queensland, roamed the hinterland of Moreton Bay and beyond, it never entered my head that it would fall to my lot to design and construct Sydney's Underground Railway and Harbour Bridge, whose proud arch, now Colossus-like bestriding the Harbour, is the most important arch yet created by man. It is divinely outclassed in beauty and infinitely outspanned only by the blue arch of heaven, and God's beautiful bow in the clouds, the rainbow.

The story of Sydney began in a little home at Marton in Yorkshire, where James Cook was born in 1728. The village of Marton is at the foot of the Cleveland Hills, where much of the iron ore for making the steel for Sydney's Bridge was mined.

Forty years later, in 1768,

"When gallant Cook from Albion sailed
To trace wide oceans o'er,"

little did he dream that his name would re-echo down the corridors of time, that his voyage would be the brilliant

success/

success it was, and that he would add our island Continent Australia to the Empire.

After discovering and exploring Botany Bay, Cook weighed anchor there on May 7th, 1770, and sailing north sighted an inlet or harbour in which there appeared to be a good anchorage, which he called Port Jackson, thus the Harbour was discovered.

After the loss of the American Colonies, the British Government decided to establish a settlement at Botany Bay, a fleet, under the command of Governor Phillip, sailed from Plymouth on May 13th, 1787, and arrived at its destination, Botany Bay, in January, 1788. Phillip considered Botany Bay not altogether suitable for the settlement, so he took a boat's crew north and explored Port Jackson, and, after examining the various coves, he decided to establish the Colony on the foreshores of a cove which he names, "Syndey Cove", in honour of Lord Sydney, the then Secretary of State. Thus Sydney, the Mother City of Australia, came into being.

The native name for the cove is "Warrung", which means "Child", and a worthy child of the Empire Sydney has grown to be. Who on that January 26th, 1788, could have foreseen that in a little over a century the commerce and shipping of the little clearing commenced that day in the bush would

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be exceeded by only four ports in the United Kingdom, London, Liverpool, The Tyne and Cardiff.

And yet, within three years of the landing, it was forecasted by Dr. Erasmus Darwin, grandfather of the eminent Naturalist, Charles Darwin, who in 1791, wrote a poem entitled, "The Visit of Hope to Sydney Cove", in which occur the following prophetic lines:-

> "Hear me", she cried, "Ye rising realms! Record
> Time's open scenes and Truth's unerring words --
> There shall broad streets their stately walls extend,
> The circus widen and the crescent bend;
> There ray'd from Cities o'er the cultured land,
> Shall bright canals and solid roads expand.
> There the proud arch, Colossus-like bestride
> Yon glittering stream and bound the chafing tide;
> Embellished villas crown the landscape scene;
> Farms wave with gold and orchards blush between.
> There shall tall spires and dome-capt towers ascend,
> And piers and quays their massy structures blend;
> While with each breeze approaching vessels glide,
> And northern treasures dance on every tide!"

Captain Cook discovered the Harbour, Governor Phillip founded Sydney, Dr. Darwin forecasted Sydney's future glory and its Arch Bridge, and it has fallen to my lot to translate Dr. Darwin's prophetic vision of the proud arch Colossus-like bestriding the Harbour into a reality of steel, concrete and stone.

To link Sydney with North Sydney, floating bridges, swing bridges, high-level bridges, subaqueous bridges, tunnels and subaqueous tube tunnels have been advocated.

Perhaps/

Perhaps the most unique proposal ever made, was to cut a canal for shipping from the Head of Neutral Bay to Lavendar Bay, to bridge this canal on the high land near Walker Street and to use the rock excavated from the canal to construct an embankment across the Harbour from Dawes' Point to Milson's Point.

The first suggestion for a Bridge to link Sydney with North Sydney was made by Francis H. Greenway, Government Architect in 1815, his proposal was to build a large fort on Observatory Hill with an advanced redoubt on Dawes' Point and to construct a bridge thence to the northern shore of the Harbour.

In letters to "The Australian" in 1825, dated April 14th and 28th, Greenway wrote --

"Whenever the Bridge as proposed is carried across to the North Shore, the roads will be made to communicate with the different farms, and a grand road to the Hawkesbury, etc., making the land, which is now good for little, at some not far distant period, of immense value, and would answer the private speculation of a private individual upon certain conditions proposed."

"Thus in the event of the Bridge being thrown

across/

across from Dawes' Battery to the North Shore, a town would be built on that shore, and would have formed with these buildings, a grand whole, that would have indeed surprised anyone on entering the Harbour; and have given an idea of strength and magnificence that would have reflected credit and glory on the Colony and the Mother Country."

The earliest recorded drawing of a bridge to North Sydney was made in 1857 by a Sydney Engineer, Mr. Peter Henderson, for a bridge from near Dawes' Point, Sydney, to near Milson's Point, North Sydney.

Mr. Henderson came to Sydney in the early fifties and lived at Miller's Point, then a choice residential district. He had served his time in the shops of George Stephenson, the inventor of the railway locomotive, and was associated in various works with the famous Brunel who built the Saltash Bridge.

In 1878, Mr. W. C. Bennett, then Commissioner for Roads and Bridges, stated that he favoured a floating bridge from Dawes' Point to Milson's Point to carry vehicles, passengers, and, if necessary, a railway train.

In 1879, Mr. T. S. Parrott prepared a sketch design of a truss bridge of 7 spans from Dawes' Point to Milson's

Point, the longest span being 500 feet.

In 1880, negitiations were opened between the Government and Mr. J. E. Garbett, representing a company which was prepared to construct a high-level bridge to the North Shore at a cost of £850,000, upon condition that the Government guaranteed, for a period of thirty years, an amount equal to 3½ per cent. upon the cost of construction. On October 26th, 1881, the late Sir Henry Parkes, the then Premier, signed a Cabinet minute to the effect that "the Ministers present (nine) agreed that Mr. Garbett's proposal, as explained in his letter, be accepted by the Government", and in March, 1882, Mr. Garbett deposited a sum of £5,000 as security. Owing to a change of Government, however, nothing further was done, and the deposit was returned in the following year.

Sir John Fowler prepared plans for a suspension bridge to Milson's Point for vehicular traffic at an estimated cost of £400,000.

Tunnel connection to North Sydney was first proposed by Mr. C. O'Neill, M.Inst.C.E., in conjunction with Mr. Gipps, C.E. His proposal was made in January, 1885, and in 1887, the Government was asked to guarantee 4 per cent. on £450,000, the cost of the two tunnels proposed --

one/

one for railway traffic, and one for road traffic.

In January, 1888, a deputation waited upon Sir Henry Parkes to urge the construction of a bridge as an undertaking fitting to mark the Centenary of the Colony.

Public agitation continued, and in response thereto, in March, 1890, the Government appointed a Royal Commission to inquire into the proposed extension of the railway into the City and the North Sydney connection. Eight schemes were submitted for connecting North Sydney by Bridge, whilst at least 4 witnesses favoured a tunnel.

The Royal Commission reported "that at present it was inexpedient to connect the North Shore with Sydney by means of a bridge or tunnel, but the Commission is of the opinion, upon the evidence before it, that, if it should be found necessary to connect North Shore with Sydney, it should be by means of a high-level bridge, and that if it were possible to throw a bridge across in one span, such plan should be adopted."

No action was taken on the report of the Royal Commission presented in 1891.

From 1896 to 1899, the North Sydney Connection was brought prominently forward by private enterprise, four bills were under consideration by Parliament, two for com-

munication by tunnel, one a roadway the other a tramway tunnel (Mr., now Sir John Sulman, F.R.I.B.A., Promoter of both) and two for communication by bridge (Mr. B. C. Simpson, M.Inst.C.E., being the Promoter for one having two main spans 500 feet long, and Mr. William Kenwood for the other, the two main spans being 700 feet long). No progress was made with any of these Bills.

After two deputations had urged that the construction of the bridge be put in hand by the Government, or, failing that, by private enterprise, the Hon. E. W. O'Sullivan, then Minister for Public Works, on January 4th, 1900, called for competitive designs and tenders. In all, twenty-four schemes were submitted, but most of them were so incomplete as to warrant little consideration. My first connection with the Sydney Harbour Bridge began in checking the calculations for these designs and tenders in conjunction with Mr. H. H. Dare, now Commissioner for Irrigation. None of the designs were satisfactory.

The Hon. E. W. O'Sullivan, Minister for Public Works in Sir William Lyne's Ministry, appointed an Advisory Board, of which Mr. Joseph Davis, now Consulting Engineer for N.S.W. in London, was Chairman. This Board called for designs and tenders on March 25th, 1901. Twelve were received, one

from/

from Messrs. Alexander Findlay & Co., Motherwell, England, was for an arch bridge of 2,100 ft. span. It was proposed to erect this arch on falsework, but knowing the many feet of soft silt overlying the rock, the Advisory Board did not think the arch could be so erected. The stresses in the various designs were checked by Professor Warren, Mr. Dare and myself, and, after a most complete investigation, the Board recommended on November 25th, 1903, the tender of Messrs. J. Stewart & Co., for a cantilever bridge from Dawes' Point to McMahon's Point with a central span of 1,200 ft., the two main piers being in the fairway. The estimated cost of the Bridge and Approaches was £1,940,050. The late Mr. Norman Selfe was Consulting Engineer to the Maxchinenbaugesellschaft Nurnberg, which firm was the author of the tender accepted.

In the absence of Mr. Dare for six months through sickness, the technical work in connection with these tenders devolved on myself. It proved an excellent training for my future work.

The Report of the Advisory Board was presented at a time of temporary financial depression, the See Ministry (into which Ministry the Lyne Cabinet had merged) went out of office, the incoming Waddell Government did not proceed

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with the recommendation made by the Advisory Board.

The next forward step was on May 11th, 1908, when the Wade Ministry, appointed a Royal Commission to make full and diligent inquiry into the expediency of providing increased and improved facilities of communication between Sydney and the suburbs on the northern side of Sydney Harbour, from the point of view of passenger, vehicular, and freight traffic, and to suggest what, in their opinion, is the best practical method of establishing direct communication between the northern and southern sides of the Harbour, which will, at the same time, avoid obstruction to Harbour navigation, and also the best route for such direct communication.

This Royal Commission presented its report on March 29th, 1909, and, inter alia, reported:-

> "The best practical and most economical method of establishing direct communication, which will avoid obstruction to harbour navigation, is by subways. A depth of 40 feet of water at low water above the subways was provided for. The railway and tramway subways should permit of rolling stock of standard dimensions being used with electricity as a motive power.
>
> "The following railing, tramway, and vehicular subway schemes are recommended for adoption:-

"Railway/

"Railway subway scheme from Lavender Bay, via Kirribilli Point (Beulah Street) and Fort Macquarie to Moore Street.

"Tramway subway scheme from Arthur Street, North Sydney, via Milson's Point and Dawes' Point, to loop at Barton Street, Circular Quay.

"Vehicular subway scheme from Arthur Street, North Sydney, via Milson's Point and Dawes' Point to connect at Pottinger Street with the new road proposed by the Sydney Harbour Trust Commissioners."

On December 14th, 1909, the railway subway scheme from Lavender Bay via Kirribilli Point and Fort Macquarie to Moore Street was referred to the Parliamentary Standing Committee on Public Works, but Parliament expired by effluxion of time in 1910 before the Public Works Committee completed their inquiry.

Obsessed by the election cry of "leg irons", the voters of New South Wales, who are cajoled to believe that every three years on election day they are the masters of the country, replaced the Wade Administration by the McGowen Ministry, the Hon. Arthur Griffith was Minister for Public Works, and during Premier McGowen's absence from the State,

the Hon. W. A. Holman was Acting Premier. During his regime on July 19th, 1911, it was announced, "Cabinet had that day decided that a definite proposal for a bridge to carry tramway, vehicular and pedestrian traffic, but not a railway, should be submitted immediately to the Public Works Committee, and concurrently with that, a proposal for a subway to connect the North Sydney Railway System with the City System."

On November 30th, 1911, Mr. Griffith moved --

(a) "That it be referred to the Parliamentary Standing Committee on Public Works to consider and report upon the expediency of connecting Sydney and North Sydney by means of a bridge.

(b) "That it be referred to the Parliamentary Standing Committee on Public Works to consider and report upon the expediency of constructing a subway from Circular Quay, via Fort Macquarie and Kirribilli Point, to Lavender Bay, for the purpose of affording railway communication between Sydney and North Sydney."

I than was Principal Designing Engineer responsible to the various Chief Engineers for the Contract Plans of all Engineering Works, roads, bridges, railways, tramways, water supply, sewerage.

I did not think that the Bridge recommended by the Advisory Board from Dawes' Point to McMahon's Point, or the subways recommended by the Royal Commission, or the two submissions made by Parliament to the Public Works Committee

were suitable or adequate to link Sydney with the North Sydney that will be.

I told the Minister that the Advisory Board's Bridge would be a menace to navigation, that the subways as proposed would obstruct navigation and were not suitable for vehicular traffic on account of the high foreshores, particularly on the northern side of the Harbour, and was given permission by Mr. Griffith to submit my design for a Bridge spanning the Harbour from Dawes' Point to Milson's Point without any obstruction to navigation as a counter proposal to the two submissions made by Parliament.

The evidence given before the Public Works Committee and the recommendation of that Committee will form the subject of my next broadcast, so if the early history of Sydney's Bridge has bored you, be wise and avoid listening in to my next broadcast.

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THE SYDNEY HARBOUR BRIDGE.

Bridge or Subway.

A great City reflects the personality of its citizens, generation by generation. Its dark spots are due to their self-interest, apathy, or lack of faith in its future, its bright spots are due to their disinterested public service, foresight and idealism.

The situation when the Public Works Committee began its Inquiry was briefly thus --

A Royal Commission in 1909 had recommended the City Railway proposed by Mr. T. R. Johnson, then Chief Railway Commissioner, for a three-track loop railway around the City, with connections to the eastern, western and northern suburbs, the trans-Harbour connections to the western and northern suburbs to be by subways providing for a depth of 40 feet of water at low water over the subways. All stations were to be underground, the Central Station below and at right-angles to the present steam terminal, Town Hall to be at the back of the Town Hall near Kent Street, Circular Quay Station to be in the water below the existing ferry wharves, St. James and Liverpool Street Stations to be located in Hyde Park, and Wynyard Station below Wynyard Square.

The subway to North Sydney commenced at Circular Quay

Station/

Station as located below the waters of the Harbour, thence via Fort Macquarie and Kirribilli was graded to connect with the existing Milson's Point Railway near the entrance to the tunnel at Lavender Bay, with the Station at Milson's Point, located deep down, 75 feet below the water level.

Another Royal Commission reported that a bridge "on account of its huge dimensions would not add to the beauty of its surroundings and would not be a desirable feature."

The Advisory Board had recommended the tender of J. Stewart & Co. for a bridge from Dawes' Point to McMahon's Point, 1,200 feet clear span, with its two main piers in the fairway, connecting with the City Railway at Wynyard Station and with the Milson's Point Railway at Bay Road Station, now renamed Waverton; the proposed North Sydney Station, located some 8 chains west of Blue's Point Road and the same distance above the foreshores of Berry's Bay, was badly placed. It would not have served the traffic of North Sydney to any appreciable extent.

I fought for fresh air and sunlight in Sydney's transport schemes, and my design for the Bridge and City Railway was for the Harbour crossing to be by bridge, not by subway, and the City Railway to be above ground as largely as possible. Central Station, as now constructed, above ground and parallel

to the/

to the steam terminal, Museum and St. James approximately as constructed, in Hyde Park, Town Hall Station to be under George Street in front of the Town Hall, Wynyard Station in Wynyard Park, both these stations are now nearly completed, above the ferry wharves. On the Northern side, the two stations were both to be above ground, Kirribilli parallel to Alfred Street between Burton Street and Willoughby Street, serving the low-level areas along the foreshores, and North Sydney Station fronting Blue Street between Walker Street and Miller Street.

The Bridge, from Dawes' Point to Milson's Point, was to span the Harbour in one clear span of 1,600 feet, without piers in the fairway.

There were many who genuinely held the opinion that connection by subway was preferable to connection by bridge, thinking that a bridge must destroy the natural beauty of the Harbour, while others just as genuinely held the opposite view, that the connection should be by bridge. There were many others whose interests were opposed to connection by either bridge or subway, and it was not difficult for them to disunite public opinion, and so continue existing conditions.

My/

My design for Bridge and City Railway was in opposition to all previous recommendations, hence my evidence had to bear the most searching criticism and be irrefutable.

The Parliamentary Standing Committee on Public Works, of which the late Mr. John Storey was Chairman, began its Inquiry on February 20th, 1912, and presented its report on July 18th, 1913; the Inquiry, open to all who desired to give evidence, lasted 18 months, and, in all, 27 witnesses were examined.

In any important seaport where the foreshores are low on either side of the waterway, the road or rail level need generally be only half the distance below water that it must be above water if carried on a bridge, as the headway under the bridge for shipping must be taken into account. In Sydney, the shores rise rapidly on either side of the Harbour, quite abruptly on the Northern side; this in itself forms a prima facie case in favour of a bridge.

In my evidence, I stressed the development which had, and would take place in the size of vessels, and the majestic floating palaces which could be expected to trade to Sydney in the not distant future, and, therefore, it was imperative not to restrict the waterway against these mammoth liners by a too little depth of water above subways, or by a too little headway under a bridge.

As/

As Allan Cunningham aptly sang in one of his ballads 100 years ago:

"The wind is piping loud, my boys,
The lightning flashing free,
While the hollow oak our palace is,
Our heritage the sea."

The future of New South Wales will always be dependent upon its commerce overseas, our primary products must find a market abroad and we must take the products of other countries in exchange, the sea is our outlet, the Harbour our heritage and the place of assembly for our ships, and neither bridge nor subway which would restrict the development of the Harbour should be entertained.

When the depth of water of 40 feet above subways was recommended in 1909, the Cunard liner, the "Mauretania", was the largest steamship afloat, she consumed 1,000 tons of coal per day to maintain her speed on her six days' run to New York. On the voyage to Australia, on account of the long stretches of ocean between ports, sufficient bunker space for coal would have been a problem, and it was stated that such mammoth coal-burning vessels could not trade to Australia.

Steam vessels burning oil as fuel, and vessels engined with Diesel Oil Engines were then in their early development and I stated in evidence that oil fuels would make it economical-

ly possible/

ly possible for the largest boats built, or likely to be built, to trade to Australia.

The size of merchant vessels trading to any port is determined by the inexorable laws of commerce, economy of transport and the demands of passengers for room and comfort, that at no distant date the largest vessels would be demanded.

I pointed out that the Harbour could be deepened to 60 feet and over, up from the Heads, and that subways limiting the depth to 40 feet should not be entertained as they would obstruct the shipping of the future.

It may not be generally known that when under weigh a vessel requires a greater depth of water than when stationary, owing to the pull of the propeller and other causes. The scend or squat of the vessel, as it is termed, increases directly with the speed and fineness of the ship's lines and inversely as the depth of water under the keel. Observations made on the "Mauretania" showed with a draught of 34'9" fore and aft when stationary, when under weigh at a speed of 18½ miles per hour, her draught increased to 37'7" fore and 38'7" aft, the squat aft being 3'10".

There is no definite rule as to the amount of squat, but when the keel of a vessel is near the bottom of the channel,

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the squat is about one-fifth of her speed in statute miles per hour.

The Suez Canal Company requires a vessel to have at least 6 feet of water under her keel, as the wash of a large vessel might cause displacement of the sandy bottom of the Canal. Allowing a 3 feet margin, for squat at a slow speed, for practical navigation, the subways would have limited the draught of vessels to 35 feet as a maximum at low tide.

The three largest vessels afloat today are the "Leviathan", the "Majestic" and the "Berengaria", their respective draughts are 40 feet, 39 feet and 39 feet, and such vessels could not have passed over the proposed subway at all states of the tide.

With a depth of 40 feet of water, the ruling grade of the roadway subway was 1 in 12 for a short length and a grade of 1 in 17 for over half a mile in length, a greater depth of water than 40 feet would necessarily steepen these grades. With a bridge, giving 171 feet headway, the ruling grade on the Approaches is 1 in 30.

To give a similar width of accomodation as provided for by the bridge, two rail and three vehicular subways would have been required, these would have cost quite £2,000,000 more than the bridge. The subways had this advantage, that they could

be undertaken one at a time, as required, whereas the whole bridge must necessarily have to be constructed and its capital cost incurred at once.

With subways there were problems of ventilation, noise and drainage which did not occur with the bridge, whilst subways had to be lighted day and night, as against only night lighting on the bridge.

Should an electric train stall below water level, ventilating machinery could supply the air necessary for the safety of the passengers, but if the train also caught fire, the air supplied would fan the flames and cause disaster.

During the Public Works Committee Inquiry, Mr. David Hay of the firm of Messrs. Mott & Hay, London, came to Sydney at the request of the Government to advise on the question of Passenger Transit in the City and Suburbs, including the connection to North Sydney. The evidence I had given at the Public Works Committee was made available to him; he concurred that connection by bridge was in every way superior to connection by subway, and the location I had chosen for the bridge was the most suitable. He gave this evidence informally to the Public Works Committee before returning to London to prepare his report.

Since/

Since the War, larger steam liners bruning oil fuel and large Diesel-engined vessels are being built. It is interesting to note that although the Harbour Trust in 1909 approved of the subway then proposed, a few years ago the Trust notified the Public Works Department that the minimum depth of water now acceptable to the Trust would be not less than 55 feet.

The bridge recommended by the Advisory Board had its two main piers 1,200 feet apart in the fairway, the southern pier would have rendered valueless Berth No. 1 at Miller's Point and would have been a serious obstruction to Berth No. 2, whilst both main piers in the fairway were a menace to navigation. They were to be founded on rock at 120 feet and 172 feet, through silt and mud, the superstructure of each pier to the underside of the deck 160 feet above High Water Mark, was to be built up of four steel columns braced together; there was always the danger of the bridge being wrecked by the collision of a large vessel with one of the steel columns of the piers.

I had the locations of these piers marked out with buoys, and, after an inspection, the Committee could only come to the conclusion given by me in evidence, that the bridge recommended by the Advisory Board would have been an hindrance and a source of danger to shipping.

The/

The final consideration was the headway required for shipping, bearing in mind the height of funnels and installation of wireless, which in 1912 was installed only on the most important passenger liners.

The headway I determined upon was 170 feet at high water over the central 600 feet. Of the 7,564 steamships of 2,000 tons burthen and over, registered at Lloyds in 1913, only three could not have passed under the bridge, but their masts could have been made telescopic. Mr. Fisk of the Marconi Company advised that a height of 160 feet should be ample provision for aerials for all time.

It is the height of funnels, however, not masts, which really governs the headway required. The "Majestic", a 60,000 tonner, is the only vessel afloat today with funnels higher than 150 feet, the tops of her funnels are 155 feet above water line. The "Bremen" and the "Europa", the two Norddeutscher Lloyd boats, recently placed in the Atlantic service, have been built with telescopic topmasts, and their funnels are about 120 feet high. The new Cunard liner at present proposed for the Atlantic service will have a funnel height of 130 feet.

The headway under the bridges across the East River, New

York, is 135 feet at high water and under the Forth Bridge, 150 feet, through which the British Fleet must pass to reach its Naval Base at Roshythe.

It is evident that the headway at high water at the centre of the Bridge, 171 feet, as now erected, is ample for future requirements of the shipping.

I submitted designs and estimates for three types of bridge, Cantilever, Suspension and Cantilever Arch, recommending the Cantilever Bridge for adoption.

It was then quite feasible to design and fabricate an Arch Bridge, but its erection was the problem. Five years later, in 1917, the Hell Gate Arch Bridge was successfully erected by cantilevering the two half-arches out from the shores, incidentally the Hell Gate Arch is 650 feet less in span than the Arch Bridge now spanning the Harbour.

On July 18th, 1913, the Public Works Committee unanimously reported --

"That in the opinion of the Committee it is expedient to connect Sydney and North Sydney by means of a bridge and they recommend the adoption of the scheme submitted by Mr. J. J. C. Bradfield, Chief Engineer, Metropolitan Railway Construction, for the construction of a Cantilever Bridge from Dawes' Point to Milson's Point carrying

four/

four lines of railway, one roadway 35 feet wide, one motor roadway 17'6" wide and one footway 15 feet wide at an estimated cost of £2,750,000, and in concluding their Report, the Committee desire to express their high appreciation of the able service rendered them during their Inquiry by Mr. J. J. C. Bradfield, Chief Engineer, Metropolitan Railway Construction."

Thus the much-debated question of bridge or subway connection to link Sydney with North Sydney was definitely determined by the Public Works Committee in favour of connection by bridge. The site of the bridge fixed from Dawes' Point to Milson's Point, the bridge to be of one clear span from shore to shore, providing for a headway for shipping of 170 feet at the centre.

In all affairs of man, there are efforts and there are results, and the strength of the effort is the measure of the result. My design was adopted in its entirety.

The then Minister for Public Works, Mr. Arthur Griffith, gave me a free hand; I had, of course, to substantiate my evidence step by step, and alone, as I had no Staff at the outset.

Reviewing the question of bridge as against subway today, there is now an outstanding example of a subway recently con-

structed under the Hudson River, the Holland Tunnel, 9,228 feet long, which provides for four lanes of vehicular traffic. Its cost, 48,000,000 dollars, or 12,000,000 dollars per lane of traffic.

There is also an outstanding example of a mammoth bridge recently constructed, the Philadelphia-Camden Bridge, 9,570 feet long, providing for ten lanes of traffic. Its cost, 36,000,000 dollars, or 3,600,000 dollars per lane of traffic. The construction costs are comparable as the subway and bridge were constructed under similar economic conditions. The cost of construction per lane of traffic on the bridge is only 30% of the cost of construction per lane by the subway.

For the year 1929, the vehicles passing through the Holland Tunnel numbered 10,977,910, and over the Philadelphia-Camden Bridge, 11,615,609. The bridge is 342 feet longer than the tunnel.

In 1929, the maintenance cost for the Holland Tunnel was 1,483,228 dollars, the cost of maintenance per lane of traffic was 370,800 dollars. The cost of maintenance of the bridge for the same year was 338,522 dollars, and, as there were only six of the ten lanes of traffic in service, the cost of maintenance per lane was 64,700 dollars, or only 17½% of the cost

per/

per lane by subway. When the ten lanes are in service, it is estimated the cost of maintenance should not exceed 55,000 dollars per lane, or about one-seventh the cost per lane by Holland Tunnel.

These comparisons of cost of bridge and subway today are interesting and substantiate the evidence given before the Public Works Committee of 19 years ago, when recommending that the linking of Sydney with North Sydney should be by bridge and not by subway.

On June 30th last, Sir John Biles, England's eminent Naval Architect in a paper on "The Draught and Dimensions of the most economical Ship", forecasted that for voyages 9,000 miles and over, the most economical ship would be at least 1,000 feet long and up to 60 feet draught.

In conclusion, Ladies and Gentlemen, to quote Rider Haggard, "Knowledge the lord is a barren grant, unless it can also be a servant; aye, a slave at command, to work good for mankind", and on the eve of the completion of the Bridge, I have the satisfaction of knowing that I led public opinion straight and that it was my evidence which influenced the Public Works Committee in making the right decision for a bridge.

My next broadcast, on September 30th, will touch on

matters/

matters leading up to the passing of the Act authorising the construction of a Cantilever Bridge or the two-hinged Arch Bridge, with abutment towers and pylons as I designed them.

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No. 3.

THE SYDNEY HARBOUR BRIDGE.

The Bridge Act.

31

In the early 'eighties, Sir Henry Parkes, in one of his stirring electioneering speeches, set a-going the imagination and expectation of the electors of Sydney when he dramatically paraphrased the call of Horatius Cocles to the Citizens of ancient Rome:

"Now who will stand on either hand
And build the Bridge with me?"

The cognomen, "Cocles", intimated that Horatius was one-eyed, but he saw his duty, and was immortalised in verse for doing it.

Introduced into the political arena by Sir Henry Parkes, the North Shore Bridge always figured in the political shop window-dressing of the day for nearly 40 years. Politicians played with the Bridge, and the electors had the political dust of the "Not Sure" Bridge thrown often in one eye, and sometimes in both.

Effluxion of time or a change of Government conveniently held the Bridge up, but if anything did appear likely to materialise the cry of City versus Country, or Bridge versus Subway, could always be raised at an opportune time.

Sir Henry was coquetting with Mr. J. E. Garbett for the

construction/

construction of the Bridge in 1881, but his Government went out of office before the matter was finalised.

To the Hon. E. W. O'Sullivan belongs the credit of making the first genuine move towards the construction of the Bridge, but the Cabinet, in which he was Minister for Works, went out of office before the recommendation of the Advisory Board could be dealt with. It was a time of financial depression, and the incoming Government did not accept the tender.

With the advent of the Wade Government, the Premier representing Gordon, an electorate keenly interested in some better means of communication between Sydney and North Sydney than the ferries, the late Sir Charles Wade appointed a Royal Commission, which recommended subways as the best practical means of connecting Sydney with North Sydney. He submitted to the Public Works Committee the proposal for a railway subway to take the Milson's Point railway traffic into the City. This subway would have served the electorate of Gordon and the railway traffic from Hornsby, but would have been of little benefit to the Northern Suburbs as a whole. Parliament expired by effluxion of time before the Public Works Committee completed its Inquiry.

The incoming Government, the McGowen Administration, which

merged/

merged into the Holman Government, then came into office.

Following the decision of Cabinet, Mr. Griffith, Minister for Public Works, submitted proposals for a suspension bridge for vehicular traffic and a subway for railway traffic to the Public Works Committee, which reported in 1913 in favour of my Bridge to take railway, vehicular and pedestrian traffic, as previously broadcasted. Early in 1914, I was instructed by Mr. Holman to proceed abroad and make myself familiar with the long-span bridges and underground railway systems in the principal cities of the world prior to my undertaking the construction of Sydney's transit system.

Among numerous other places, I visited Ambridge, where the American Bridge Company was fabricating the Hell Gate Arch, and saw the first two sections of that arch fitted in the workshops; they butted perfectly. I also visited the Dominion Bridge Company's works near Montreal, where the Quebec Bridge was beign fabricated.

During my visit to Canada and America, I met Gustav Ludenthal, Ralph Modjeski, Charles Schneider, Colonel Monsarrat, Phelps Johnson, George Duggan and George Porter, the doyens of the Canadian-American Bridge world. I also met Mr. Charles McDonald, then in retirement, who had built the Hawkesbury Bridge. As a student at the University, I had met him at

"Blink Bonnie", as he had named his residence after his Canadian home. We had each seen a quarter of a century go by, but he was the same kindly gentleman to me as he was when I, a youth at the University, visited his bridge camp at Brooklyn at my week-ends in 1887 and 1888. "Blink Bonnie" is still the name of a house near Hawkesbury Station.

In England I visited many most interesting works, among others the steelworks of Dorman, Long & Co., Ltd., at Middlesbrough -- they then did not fabricate bridges -- also the bridge shops of the Cleveland Bridge Company at Darlington, and Sir William Arrol's works at Glasgow. I also visited France and Germany. One Sunday morning I left Cologne for Hamburg with a Mr. Kavanagh, then in the employ of a German Company, to see some chrome nickel steel bridges at Hamburg. The railway carriages were corridor cars, half first, half third. We entered the centre compartment so as to avoid riding over the bogie. The German conductor had his own idea of loading the train; it was to load the end compartment first, then when full to open up the second compartment, and so on until the carriage was full. He came along and wanted us to shift from the centre to the end compartment; but we didn't, and he went out muttering in German, "It is no use arguing withthose thick-headed fools of English." The German nation

realised/

realised that fact during the next four years, as war broke out almost immediately.

On my return to Sydney I reported on February 24th, 1915:

> "To secure the cheapest and most efficient bridge the following course is recommended --
>
> "Alternative tenders to be called for local manufactyre and for importation on plans and Specification fixing the essential features only, and leaving the details of construction and the choice of steel to tenderers. The successful tenderer to complete the working plans to the satisfaction of the Public Works Department."

During the Holman Administration, the Hon. John Cann, who succeeded Mr. Griffith as Minister for Works, twice passed an Enabling Bill through all its stages in the Legislative Assembly in 1916. In the Legislative Council, however, the Bill was rejected, once at the second reading stage, and, on the second occasion, at the third reading stage by three votes only.

For the next three years the War precluded action, but I have in my files a letter from the Secretary to the then Premier approving of the arrangements he had asked me to formulate for laying foundation stones on both sides of the Harbour. But, alas, for the foundation stones! The aeroplane in which he was electioneering side-slipped or nose-dived politically in the Cootamundra electorate and a new Government, the Storey

Government, came into office.

In the previous Administration an Electoral Act was passed providing for proportional representation; each electorate had either three or five members. Three of these electorates -- two having five members and one having three members, i.e., thirteen members -- had of necessity to be interested in the construction of the Bridge to secure election. I saw the advent of the Bridge was possible, as thirteen members out of ninety, parties notwithstanding, would have to vote for its construction, and in any fairly evenly divided Parliament it should be possible to pass the Enabling Bill through both Houses.

Mr. W. R. Fitzsimons, then President of the Kuring-gai Shire Council, and myself discussed ways and means to secure the passing of an Enabling Act, and he, as Shire President, requested the then Mayor of North Sydney, the late Alderman A. E. Whatmore, to summon a meeting of the Members of Parliament and Aldermen on the Northern side of the Harbour interested in the construction of the Bridge.

I prepared the scheme put before the meeting briefly for a land tax on the unimproved capital value of lands in the City and Northern Suburbs, and the tax to operate as soon as

the Act was passed, instead of upon the completion of the Bridge as in the two previous bills. The meeting passed the resolutions unanimously, and in August, 1920, went as a deputation to the Premier, the Hon. John Storey, urging the construction of the Bridge. The Premier told the deputation that it was the first time in his Parliamentary career that he had known anyone to come and ask to be taxed, and as the electorates did not favour his political leanings he would be pleased to oblige them. After the deputation had departed I asked the Premier if he really intended to call tenders for the Bridge, and he assured me that he did.

I then started drafting the Specification and the plans necessary for tenders to be called for the Cantilever Bridge, and at the end of the year, 1920, I received instructions from Mr. Estell, Minister for Works, at the Premier's Office, that plans and Specifications were to be ready to enable tenders to be advertised on September 30th, 1921. Mr. Storey died on October 5th, 1921, and the Hon. James Dooley became Premier until April, 1922.

Mr. Estell introduced the third Bridge Bill, which passed the Legislative Assembly in 1921; it stood for its second reading in the Council when Parliament dissolved. World-wide

tenders were advertised on September 30th, 1921; in accordance with the terms of the Specification, I visited Canada, the United States and Europe, to give information on the technical, industrial and financial matters involved.

Interested by the erection of the Hell Gate Arch which I had seen in course of fabrication and erection, I had investigated the design of a 1,650 feet arch and the problem of its erection, and was convinced an arch could be successfully erected. The arch bridge had to be longer in span than a Cantilever Bridge, to allow headway for the roads on the foreshores of the Harbour, which would have to pass under the steelwork of the arch.

I discussed the possibility of building an arch with various Bridge Companies -- the Strauss Bridge Company, the McClintic Marshall, the American Bridge, the Canadian Bridge Company, Sir William Arrol and Company, the Cleveland Bridge Company, Darlington, England and others in Europe. I did not see the firm of Dorman, Long & Co., Ltd., on this visit to England in 1922, nor meet any of their consultants. The firm was not then very interested in bridge building. Three firms, the McClintic Marshall, Sir William Arrol and Co., and the Cleveland Bridge Company, definitely stated they would tender

for/

for an Arch Bridge, whilst other firms intimated that they might do so.

After my departure for Sydney in March, 1922, an election was held; the Fuller Government replaced the Dooley Administration, Sir Thomas Henley becoming Minister for Works. Later he resigned, and was succeeded by Mr. Ball, who was Minister for Works on my return to Sydney on October 3rd, 1922, when I obtained Mr. Ball's approval to include an arch as well as a cantilever bridge in the Bill then being discussed in the Assembly.

Plans of both Bridges were submitted to Parliament -- the Arch Bridge, with abutment towers and pylons, and the Cantilever Bridge. I assured the Minister that the Arch Bridge would be at least £350,000 cheaper than the Cantilever Bridge, which tenders proved it to be, and that it had other advantages.

The Fuller Government asked the Railway Commissioners as to the urgency of the Bridge from their point of view, who, under date May 17th, 1922, furnished a statement of what the position would be in 1931, assuming the percentage increase of the previous ten years was maintained. The decade, 1911-1921, covers the War period, and it is held, therefore, that such is on the low side.

They/

They estimated the tramway passengers on the North Sydney system would increase from 31 millions to over 56 millions, the railway passengers from 13 millions to over 30 millions, and the total ferry traffic from 40 millions to 58 millions, and that the population of the Northern Suburbs would increase from 166,354 in 1921 to 290,460 in 1931. The report further stated --

> "The present means of transportation to and from the Northern Suburbs does not adequately meet the requirements of the growing population of that district, and it is considered that the modern method of passenger transportation, namely, an electric railway service with no dead-end or terminals, should be adopted at the earliest possible date.
>
> "The congestion of both the passenger and vehicular traffic on the Northern side of the Harbour has at the present time reached saturation point, and it can only be relieved by the immediate construction of the Bridge, which will also open up the Northern Suburbs and give them direct railway communication with the City and Eastern and Southern Suburbs. Milson's Point Railway Station, which has only three platforms and a dead-end, can be dispensed with.
>
> "The Sydney Harbour Bridge is an integral part of the City Railway Scheme, and its construction will considerably relieve the congested traffic which must obtain at the Central Station until its completion.
>
> "Assuming that the Bridge, if started upon, could be opened for traffic in eight years, it would be difficult to find a stronger reason for the urgency of its completion than the figures shown in the above statement relating to the Northern side of

the Harbour only, and, in view of all the facts, the Commissioners are of opinion that the Bridge should be proceeded with at the earliest possible date."

In September, prior to my returning to Sydney, the Bill had been introduced into the Assembly for the fourth time as a non-Party measure by Mr. Ball, and after a somewhat stormy passage passed the Assembly.

At one stage the Bill met with a setback, when the then President of the Kuring-gai Shire, Mr. Norman McIntosh, arranged for a monster meeting at Chatswood to urge the Government not to drop the Bill. Mr. Bavin, as Attorney-General, attended on behalf of the Government, and assured the meeting that the Bill would not be dropped.

In the Legislative Council, Sir Joseph Carruthers ably guided the measure, where it passed the second reading debate by 28 votes, and on November 24th, 1922, an Act to sanction the construction of a high-level Cantilever or Arch Bridge across Sydney Harbour by connecting Dawes' Point with Milson's Point, together with the necessary approaches, railway connections and other works connected therewith, received the Governor's assent.

Thus, 106 years after a bridge was first proposed by Francis Greenway, and 40 years after Sir Henry Parkes intro-

duced the Bridge into the political sphere, "the wings of dawn were beating at the break of day", as the sanction of Parliament had been obtained for the construction of the Bridge.

In the annals of the past, each silver lake, each brimming river, both mountain and forest, have their stirring story to tell, and, with the Bridge, its authorisation by Parliament enabled its romance to materialise into a reality of simplicity, strength and beauty, which I will describe in my next broadcast on October 14th.

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THE SYDNEY HARBOUR BRIDGE.

Design.

At the back of every great work is the mind of its Author, whose conceptions either ennoble his work or make it commonplace, and in bringing to fruition my creations the Bridge and City Railway I have endeavoured to depict in steel, concrete and stone through the City and across the Harbour, the artistry and the poetry of the Science of Engineering in a manner worthy of the Mother City of Australia and to weave in them as the characteristics of their design, simplicity, beauty, service!

Before the design of the Bridge could be undertaken, a careful study of the site was essential. In the Triassic era, some hundreds of millions of years ago, the site of Sydney was in the making, the Narrabeen shales were covered with colossal sand hills, the area sank beneath the waters and the sand hills consolidated into vast beds of sandstone. Sediment and fine slimes washed down by fierce, tumultuous storms collected in the ever-shallowing basin and became the Wianamatta shales which overlie the Hawkesbury sandstone. Dry land appeared, the area rose above sea level, later, the earth convulsed with volcanic activity, dykes and craters of molten basalt were forced through the shales and sandstones. On the southern Bridge Approach near Grosvenor Street, a dyke

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of decomposed basalt was met with, here the sandstone was baked into a hard metal by the fierce heat of the erupted basalt.

To investigate the strata, 15 years ago I had bores sunk to a depth of 80 feet; the cores of these diamond drill bores showed that the sandstone had not been faulted by any of earth's convulsions, that the rock below water on the foreshores had not been fretted away by the action of wind and water, there were no shelves of rock, undercut, and overhanging the rock below, as can be seen in the hills around Sydney.

On the foreshore line, rock was found on both sides of the Harbour at a distance of several feet below mean sea level, but about 30 feet back from the foreshores, the rock was above water level. The rock is in deep beds with a few inches of softer sandstone between the beds. One bore, about 33 feet below mean sea level on the southern side, went through a bed of shale 2 feet thick.

Having obtained a detailed knowledge of the underlying strata, I fixed the span of the Cantilever Bridge at 1,600 feet and of the two-hinged Arch Bridge at 1,650 feet between centres of main piers. To ensure the piers would never be undermined, I had an area of 10 acres reserved at the site of each main pier against coal-mining; there is ample space

between/

between these areas to enable coal-mining operations to proceed down the Harbour.

The next feature in the design was the arrangement of the deck. Mr. Johnson, Chief Railway Commissioner, had asked for four lines of railway and these spaced side by side with a 35 feet roadway gave an economical width, 98 feet 6 inches between centres of the main trusses. Twenty years ago, motor traffic was fast coming to the fore, so I provided for a motor roadway 18 feet wide on the eastern side outside the main girders, and on the western side a footway 15 feet wide.

Tenders were called in 1921 for a Cantilever Bridge of 1,600 feet span with this deck arrangement, but a re-arrangement of the railway tracks at Wynyard Station enabled me to re-design the deck as now constructed, viz., combining the two roadways and to space the railway tracks in pairs on either side of the central roadway 57 feet wide between kerbs, providing for six lanes of traffic each 9 feet 6-inches wide, with two footways each 10 feet wide outside each pair of tracks. On the Arch, the hangers are 98 feet 6 inches apart, so between the hangers there is the central roadway, 57 feet wide, with a line of railway track on each side of the roadway, outside each hanger is another single line of railway and the footpath 10 feet wide; on the

Arch, the total width of the deck is 160 feet, or twice the width of Macquarie Street.

Concurrently with the deck arrangement, the loading had to be determined which the Bridge would ultimately have to carry, and for which it would have to be designed. When the agglomeration of States becomes a real Commonwealth, and the break of gauge question is settled, the Transcontinental Express will start at, say, Rockhampton on its 4,000 mile run to Fremantle and can pass through Sydney via the Sydney Harbour Bridge, shortening distance by several miles. The same carriages will run right through, the steam or electric locomotives changed where required. Sydney, Melbourne and Adelaide will, in effect, become wayside stations.

The Transcontinental Express can, and should, at no very distant date, be run electrically from Brisbane to Melbourne, using electricity generated by hydro-electric power stations on the Clarence, Shoalhaven and Snowy Rivers, and by coal power stations near Ipswich, West Maitland, Sydney, Port Kembla and other localities using the Yallourn brown coal in Victoria. The Bridge is designed to carry this traffic.

The main arch span is designed for a live load of 12,000 lbs. per lineal foot with 10% in addition added for the impact caused by the surging of the trains, in all a total live

load/

load of 10,000 tons, for a cyclone raging at 100 miles per hour, equivalent to a wind pressure of 30 lbs. per sq. ft., for the braking force, that is, the push forward on each railway track of 300 tons should an electric train at high speed have to be emergency braked on the Bridge, also for the stresses caused by a rise in temperature of 60° or a fall in temperature of 60° below normal temperature. The maximum length of train load is taken at 1,100 feet, the minimum length, 300 feet.

The Sydney Harbour Bridge is the only Bridge in Australia on which braking girders have been provided. They are necessary on account of its long span.

Cross girders, hangers and deck members are designed for a live load of 100 lbs. per sq. ft. on the footways and roadway, the roadway in addition is designed for the concentrated loads of a motor truck 24 feet by 8 feet weighing 54,000 lbs., front axle load, 18,000 lbs., back axle load, 36,000 lbs., each of the four railway tracks are designed for two coupled electric locos. on each track, followed by a train 1,000 feet long, weighing 1 ton per foot run. The two locomotives weigh 360,000 lbs., and have maximum axle loads of 56,000 lbs. Reasonable provision has been made for future traffic.

In addition to the railway, tramway, vehicular and pedestrian traffic, the wracking by storm, by heat and cold,

and/

and the braking of trains, the steel arches have to carry their own weight and the weight of the deck.

The decking on the railway and tramway tracks consists of ironbark sleepers sheeted with tallow wood planking, the floor of the footways is mastic asphalt, and of the roadway, coke concrete carried on steel decking plates, the wearing surface above the concrete is Rock Asphalt.

In designing the deck, it may be of interest to say that ordinary bluemetal concrete weighs 150 lbs. per cubic foot, coke concrete 92 lbs. per cubic foot, the difference in weight between bluestone and coke concrete on the roadway would have been 1,700 per lineal foot of Bridge, my investigations showed that a dead weight of 1 lb. per foot run over the whole length of the Arch would require about half a ton of steel in the arch trusses, hence I decided to use coke concrete on the roadway, thus saving about 1,000 tons of steel in the design, or over £60,000 in the cost of the Bridge.

The steel decking plates, after scraping and cleaning, receive two coats of neat cement wash, coke concrete in and above them is then placed and consolidated to a depth of 4 inches above the top of the troughing, and after the concrete has thoroughly set, and when dry, the upper surface

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of the concrete is sprayed with emulsified bitumen to form a waterproofing. The concrete is then covered with 2 inches of rock asphalt powder. Coaked at Wongawilli and Bellambi, the coke used is hard, clean metallurgical coke, quite free from cinders and clinker, and the sulphur in the coke is less than half the amount which research on cinder and clinker concrete showed could affect steel if the surrounding concrete was continually damp. Water cannot percolate into the concrete through the asphalt surface and seal coat of bitumen, and, even if it did, the sulphur content is not high enough to affect the steel.

Before finalising the proportions of the coke concrete, I carried out a series of experiments and found that by using 15 parts of crushed coke $1^{1}/4$" to $^{3}/8$", by screening out all pieces between $^{3}/8$" and $^{1}/4$", and using 11 parts of the coke from $^{1}/4$" down to the finest dust, with 4 parts of Kandos Cement, an excellent concrete resulted. Blocks cut from the deck after it was laid have a compressive strength of 3,200 lbs. per sq. in., or over, at 28 days. Laboratory tests give 4,000 lbs. per sq. in.

The total weight of the arch span, steel, timber, concrete and asphalt complete, is 43,000 tons, of which 37,000 tons are steel. One lb. of steel has a volume of about

$3^{1}/2$ cubic/

3 1/2 cubic inches and in the Bridge there will be about a quarter of a million cubic feet of solid steel.

The severest tempest experienced in New South Wales was the Dandenong Gale when the wind reached a velocity of 120 miles per hour, equivalent to a wind pressure of 43.2 lbs. per sq. ft. The Bridge would be quite stable should such a storm occur again.

The hottest day recorded at the Observatory, Sydney, was 108.5 degrees in the month of January, and the coldest day 35.9 degrees in the month of July. The sun beats on the exposed plates of the Main Bridge members, but the interior ones are in shade so the exposed side of a member can be 25 degrees hotter than the side away from the sun, this had to be allowed for in designing the Bridge.

Of the steelwork in the Bridge, 62 1/2% is required to carry the dead weight of the Bridge, 25% for its live load, 5% for wind pressure, 5% for the effect of temperature, and 2% for braking of trains.

The next point in the design of the Bridge was to fix the deck level at the centre of the Bridge. After the arrangement and loading on the deck was decided, the cross-girder could be designed and its depth fixed, which added to the headway of 170 feet required the deck level at the centre of the Bridge to be 190 feet above High

Water,

Water. Having determined this level, and knowing the rail level at Redfern Station on the City side and Bay Road Station on the Northern side, and the street levels, I was able to determine the levels of the railway stations, viaducts, bridges and subways from Redfern through the City to Waverton.

When fixing the skyline of the roadway of the Bridge and the above ground portions of the City Railway, I made a study of how I could best add a picture of orderliness, beauty and grandeur to this picturesque City and, at the same time, show the panorama of Sydney to the countless millions of people who will traverse the Bridge.

As located by me, the four Bridge railway tracks connect with the Milson's Point Line about 200 feet on the Milson's Point side of Waverton Station. Soon after leaving that station, they enter two double-track tunnels and pass under "Graythwaite", the Church of England Grammar School grounds and Blue's Point Road, to the first station -- "North Sydney" -- situated in open cut between Miller and Walker Streets. The other station -- "Milson's Point" -- is situated in front of the old North Sydney Town Hall. The four railway tracks then traverse the Bridge, and, near Argyle Street, run underground in pairs below the Bridge Highway and junction with the City Railway at Wynyard

Station/

Station, a length of 2 miles 33 chains, from Waverton Station.

The roadway on the City side commences at Wynyard Street, York Street is widened from 60 feet to 81 feet from Grosvenor Street to Wynyard Street; Kent Street is widened to 81 feet northward from Napoleon Street to Gas Lane, whilst York, Clarence and Kent Streets are connected, near Grosvenor Street, by a Crescent to the Bridge Highway, an 80 feet roadway flanked with two 16 feet footpaths located along the line of old Princes Street at the Bridgehead. Between York Street, Kent Street and the Crescent, will be two parklets to give uninterrupted vision to the motor traffic. From Argyle Cut across the Bridge to Alfred Street, North Sydney, no buildings will flank the roadway, which consequently, is narrowed to 57 feet wide between kerbs, the roadway reaches the existing surface at the intersection of Alfred and Junction Streets, and will be continued along Junction Street widened to 100 feet to the intersection of Blue Street with Walker Street thence by a new road to the Lane Cove Road, now being constructed by the Main Roads Board.

At Milson's Point Station, the Bridge roadway, 57 feet wide in the clear, is located between the two pairs of railway tracks. Milson's Point Station has one island platform on each side of the roadway, the platforms being connected

by/

by a concourse beneath the roadway. The roadway is graded more steeply than the railway, and just before reaching the existing surface near Junction Street, it passes under the two easternmost tracks.

The materials of which the Bridge would be constructed then received consideration. The materials I selected were granite, concrete and steel.

Granite was probably the first material to solidify on the earth's crust, the strongest and most beautiful building stone, which has withstood the ravages of time for thousands of years as exemplified in those prehistoric works of man still extant; concrete is man's artificial stone, and steel is man's masterpiece, the strongest and most reliable yet manufactured by him.

I selected Moruya as the most suitable place from which to obtain the granite. The outcrop is on the bank of the Moruya River about $1\frac{1}{2}$ miles from the town and about the same distance from the river entrance, and 170 miles by sea from Sydney. The appearance of the granite was in its favour, the black biotite mica, giving the stone a pleasing appearance, sparkling in the sun and so enhancing the beauty of the white quartz and white felspar. The quality of the granite was all that could be desired; tests showed it to have a crushing strength of at least 1,100 tons per sq. ft.

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This quarry is owned by the Government.

Steel is, in general, a combination of iron with small percentages of carbon, manganese, silicon, and alloyed with other metals as desired -- carbon increases the hardness and tenacity of iron, but renders it less ductile and more liable to fracture under sudden shock; manganese makes steel tough and workable; silicon adds strength and soundness. Nickel increases the strength and elasticity, but adds about £10 per ton to its cost; chrome nickel steel made from ore mined at Mayari, Cuba, has the strength of nickel steel, but is less expensive; whilst chrome nickel vanadium steel Vibrac steel was developed in England during the War, but its cost and the difficulty in rolling it militates against its use for Bridge construction.

The concrete consists of granite or bluestone metal, Nepean sand, and Portland Cement mixed in varying proportions to give the strength and class of work required. For example, the concrete under the main bearings had to be especially good.

A series of experiments were carried out by me to ensure the best result. The concrete specimens were tested in the 100-ton testing machine at the University by Professor Miller.

The concrete decided on consisted of 9 cubic feet of

graded/

graded granite aggregate, 3 cubic feet Nepean sand and 375 lbs. Kandos cement mixed with 135 lbs., or 13 1/2 gallons of water, and the strengths obtained averaged 6,780 lbs. per sq. inch, or 436 tons per sq. ft. at 28 days, and 8,050 lbs. per sq. inch, or 517 tons per sq. ft. at three months.

Australia manufactures a cement equal to any in the world, and by using it in a scientific way any desired strength of concrete can be obtained.

My next broadcast will consider further problems on the design of Sydney's Bridge.

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THE SYDNEY HARBOUR BRIDGE.

Design (contd.)

The calculation of the stresses in the various members of the Arch is based on the method of determining the elastic deformation of a structure at any point as originated by James Clerk Maxwell, first Professor of Experimental Physics at Cambridge University; to which chair he was elected unopposed in 1871.

Clerk Maxwell's original investigations in the realm of physics, particularly electricity and magnetism, went far towards placing those sciences in the proud positions they now occupy.

The following lines are attributed to Clerk Maxwell --

"There is no stress, however great,
Can stretch a cord, however fine
Into a horizontal line
That shall be absolutely straight."

Maxwell showed that the elastic deformation of a framed structure at any point was equal to the sum of the products for each member of the strain in the member, multiplied by the stress in the member under unit load, applied at the point, and in the direction of the required deflection.

From this the stresses in a two-hinged arch may be determined. In a two-hinged braced arch, the vertical reactions are determinate by ordinary statical methods. The

horizontal/

horizontal thrusts at the bearings are indeterminate, the only relation determinable is that the two horizontal reactions against the truss must be equal under vertical loads. The value of the horizontal reaction can be determined by consideration of the relative deformations of the structure under applied load, with one hinge removed, as against the deformation required from the horizontal reaction to restore the hinge point to its correct position.

The horizontal reaction has the value obtained by dividing the horizontal deformation, hinge removed, by the deformation under unit horizontal load applied at the hinge point. Having determined the horizontal reactions, the stresses can be evaluated.

The Arch I was designing was a step much in advance of anything yet attempted and, bearing in mind the primary stresses and the secondary stresses unavoidable in a structure of this magnitude, an arch 650 feet longer in span than Hell Gate Arch, the longest arch then attempted, and, in addition to the four lines of railway on the Hell Gate Arch, Sydney's Bridge had to carry a 57 feet roadway and two 10 feet footpaths, particular care had to be given when determining the unit stresses which could be allowed in the steel members of the Bridge.

For/

For riveted members constructed in carbon steel, I fixed the working stress in tension at 18,000 lbs. per sq. inch, in silicon steel at 23,500 lbs. and in nickel steel 26,100 lbs. per sq. inch, the allowable unit working stresses in compression, bearing, bending and shearing were similarly proportioned.

These allowable unit stresses were fundamentals in determining the sectional areas of the various members after the stresses had been calculated.

Where the steelwork of the Bridge would be fabricated was another problem in its design. Prior to the year 1926, when Dorman, Long & Co., Ltd., had established their workshops at Lavender Bay, there were no bridge fabricating shops here which could undertake work of this magnitude, the largest Bridge yet attempted anywhere.

Would tenderers be prepared to erect workshops in Sydney, or desire to undertake the fabrication in their workshops in Great Britain, or America. If fabricated abroad, the lengths and weights of the members to be transported to Australia had to be within the range of the crane power on the shipping and on the wharves for loading and unloading, and to be of such lengths as could be stowed into the holds of the transporting vessels. I investigated this phase in 1914, and decided on a panel length of 50 feet, but gave

tenderers the option of increasing the panel length if they desired. If fabricated abroad, Customs duty and freight, and the difficulty of transport, had to be offset against the cost of erecting workshops in Sydney and the greater cost of wages, and lesser hours of labour here. If fabricated in Sydney with shops adequately equipped with crane power, the number of panels and thus the number of field joints, and consequently the erection cost, could be reduced. The panel length was largely an economic problem.

The length of the steelwork between the abutment of the arch over Fitzroy Street and the abutment of the arch over York Street North was fixed by me at 3,770 feet. I then located the position of the abutment towers and pylons, which fixed the position of the Arch span, and provided for four approach spans each consisting of four girders on either side of the abutment towers and pylons.

Having examined the site, taken bores, determined the traffic which the Bridge would ultimately have to carry, and the loading to be provided for, designed the deck, fixed the headway for shipping, graded the City and Suburban Electric Railway System, of which the Bridge is an integral link, fixed the location of the Bridge and Approaches definitely, decided the materials to be used in the construction of the

Bridge, the method of calculation, the allowable unit stresses, and considered the place of fabrication, my calculations were undertaken for an Arch Bridge of 1,650 feet span centres of main bearings, divided into 33 panels of 50 feet each. The Arch had a rise of 370 feet from centres of bearing to centre of lower chord. The Arch trusses were 60 feet deep at centre and 180 feet deep at abutments spaced 98 ft. 6 ins. centre to centre. The headway for shipping was 170 feet over the central 600 feet and 160 feet over 1,200 feet.

The chord members of the arches were made up of four web plates with upper and lower flanges of angles and plates, with diaphragms provided with manholes for access, the Arch trusses braced together by top and bottom lateral systems of bracing, the hangers carrying the deck built up of plates and angles.

My scheme of erection was to cantilever the half-arches out over the Harbour, using the material for the hangers and other members to hold back the half-arches, the abutment towers to support powerful jacks which would when released allow the half-arches to meet on a pin at the centre panel.

The architectural features of my design of the Main Bridge are the abutment towers and pylons, and the approach piers, all faced with granite masonry, and of the Approaches, the series of arch spans from Central Station to Waverton.

All/

All streets are crossed by arches.

There are six arch spans on the Northern Approach, over Euroka Street, over Arthur Street, a most beautiful arch, 120 feet span, in reinforced concrete carrying the railway tracks over Lavender Street, along which street via Union Street, a new road, will eventually lead up the valley of the Lane Cove River and open up most beautiful residential country, a steel arch span, 220 feet span, across the Bridge Highway, so that vehicular traffic to and from the Bridge can have uninterrupted vision and thus the greatest degree of safety, then an arch bridge across Burton Street and one across Fitzroy Street adjacent to the end of the steelwork. The footways from the Bridge reach street level at Burton Street via the Bridge Stairs.

On the south side there are three arch spans at the end of the steelwork, Argyle Cut is crossed by an arch span, the old bridge had to be removed as it was underneath the new bridge and had reached the limit of its usefulness. At Argyle Cut the four rail tracks here, in pairs on either side of the roadway, enter into single line tunnels and run underground to Wynyard Square Station. The footways from the Bridge here connect with upper Fort Street and York Street North.

On the south side, the roadway is above the rail tracks,

from/

from Argyle Cut to Wynyard; on the north side the rail tracks are above the roadway. There are no level crossings and everything has been done that is possible for the safety of all classes of traffic.

The Harbour foreshores from Lavender Bay to Milson's Point with its wealth of wild flowers was a beauty spot in the forties of last century and I have proposed that the area surrounding the steelwork on the northern side and the Harbour foreshores from the vehicular ferry at Jeffrey Street to Lavender Bay, be, on completion of the Bridge, again transformed into a park, with our native trees and flora the principal features.

Grassed lawns, with a little statuary on the water front, the cliffs ornamented with flowering creepers and shrubs to provide masses of colour as a background, would transform the present industrial area into beautiful gardens.

The area above the cliffs to be also entirely remodelled. Residential flats and other buildings in Italian Renaissance to harmonise with the gardens below could be constructed here in charming surroundings, with fine arcaded walks on the edge of the cliffs above the waters of the Harbour. Treated broadly, these walks, flanked with green and garden bloom, could be made most picturesque spots, and most delightful

resorts/

resorts for the residents during the long summer evenings.

Portions of the walks could be covered in with pergola roofs supported by dark hardwood timbers and plain white rouchcast arches to harmonise with the buildings in the background and in keeping with the scheme of ormanentation in the gardens below.

The area under the steelwork on the northern side will become parklands, whilst between the abutments of the 120 feet and 220 feet arch spans "The Grotto" has been planted with tree ferns; a simple and beautiful touch of nature at these two handsome arch bridges.

On the south side, the Bridgehead consists of two small parklets, grassed and planted with a background of native trees, Grevilleas, Silky Oaks, one bearing honey-coloured flowers, the other red flowers, with Bottle Brushes, the only shrub in the world, as far as I am aware, which numbers its flowers from its first bloom. Where flowers have been, seed pods follow and remain forever.

The grounds of the Girls' High School will be extended to the Bridge Avenue, and about half an acre added to the school area.

Where foot traffic would have to cross the vehicular or tram traffic, subways have been provided, so that children

and/

and pedestrians need never be in danger from the roadway traffic. Passenger subways will connect York, Kent and Clarence Streets with the footways on the Bridge Highway, a passenger subway will take pedestrians from York Street North to Upper Fort Street below the traffic facilities on the Bridge, whilst at North Sydney Station, passenger subways will cross beneath Blue Street for the safety of pedestrians.

This great Bridge in the Mother City of Australia across one of the most beautiful Harbours of the world, and in a setting unparalleled by any of the world's famous bridges, although primarily utilitarian, should be a work of art to which Science has lent its aid. The elaborate calculations necessary to bring its fabric into being do not make a great bridge, I have various volumes of calculations prepared by me years before tenders were called, investigating all types of bridges, and numerous volumes prepared by my Staff under my direction since the Contract was let. These do not make a great bridge. It is only with a broad sense for beauty and harmony, coupled with wide experience in the scientific and technical field, that a bridge, even to its smallest details, expressing the ideals of simplicity, beauty, service, can be created. Within six months, the Bridge will be opened for service, and the world will then pass judgement on my creation.

To/

To revert to the calculations, when estimating the tonnage of steel, the weight of the arch had, in the first instance, to be assumed and trial calculations made to check its weight. Based on the unit stresses, the sectional areas of the various members were computed and the first tried weight of the arch obtained, which was more accurate than the weight assumed. After several sets of calculations had been performed, using each successive estimated weight as the basis of the next trial, the tonnage of steel in the arch, based on carbon steel for the deck and lighter members of the trusses and nickel steel for the heavier members, was estimated by me to be 46,600 tons, of which 17,120 tons was nickel steel.

The quantities of granite masonry in the piers, abutment towers and pylons, the concrete backing, excavation and all other quantities were computed and an estimate for the steel Bridge, 3,770 feet in length based on manufacture in New South Wales, was prepared and submitted to the Minister sealed in an envelope and opened by him on the day tenders were opened.

My estimate for the construction of the Arch Bridge, exclusive of Approaches, was £4,329,520, and for the Cantilever Bridge, £4,704,840. The Approaches were estimated at £1,900,000, a total of 6 1/4 million pounds for construction, and the construction costs of the Bridge will be within my estimate.

Before/

Before concluding my broadcast tonight, may I say that my work in connection with the design of Bridge and City Railway was submitted by me in 1923 as a Thesis for the Degree of Doctor of Science in Engineering. The Examiners, Sir John Monash, Professor Chapman, Faculty of Engineering, Adelaide University, and Professor Warren, reported that the qualifications of the candidate were exceptionally meritorious and recommended that I should be granted the Degree with first-class honours and the University Medal, the highest honour the University awards. Extracts from the Examiners' reports read --

> "These works are undoubtedly of exceptional magnitude, being in some respects unique in engineering practice; and the manner in which the Author has discussed and set forth the theory and practice bearing upon them is of a masterly character, amounting, in my opinion, to a substantion and valuable contribution to the technical literature upon the subjects treated, and to an important advance in Engineering Science."

> "The Arch Design provides for a clear span of 650 feet greater than in any arch yet built in any part of the world. Moreover, the masterly discussion of the problems and the comparison of the relative merits in my opinion, constitute a distinct advance in Engineering Science."

The many problems involved had all to be solved by me before Plans and Specification could be undertaken and an estimate of cost prepared to enable tenders to be called.

The year 1931 marks the completion of the Bridge except

in/

in a few minor details and is the centenary of the discovery of Michael Faraday, who in endeavouring to reach a deeper understanding with nature, the sole aim of every true Scientist, found that just the passage of a copper wire between the poles of a magnet was sufficient to induce an electric current in it. The electricity which is being used today in our everyday life is obtained by the momentary currents observed by Faraday, but generated with such extreme frequency that when collected by suitable mechanism they form a perfectly steady flow.

When you see the brilliance of the lighting on the Bridge, the electric trains, trams and motor cars traversing it, the trains and trams automatically controlled by the signalling, the fairy land as you view the street lighting and the lighting of Sydney's buildings from the deck of the Bridge, the electric power used in Sydney's everyday work by lifts, cranes and other machinery, think of Michael Faraday, the brilliant son of a poor blacksmith from Yorkshire, whose research made all this possible.

Earlier in this broadcast I pointed out how the research and the theory founded on that research by James Clerk Maxwell, born in 1831, made the design of the Bridge possible.

In the creation of Sydney's Bridge, the labours of many

pioneers/

pioneers of Science have been made use of, the applied Science of Engineering harnesses the boundless resources of nature for the use and service of mankind.

As in the old Grecian Games, a laurel crown, only, as the prize, a runner in the torch race had to carry a torch and keep it burning as he ran, and when he was exhausted hand it still alight to the next runner in the relay. So life proceeds from life and from life only, this old world strains and pulses with new life and vigour as each generation hands on its torch to the next generation. The well-known line from the Latin Poet, Lucretius, "Quasi cursores vitai lampada tradunt", "Like runners they hand on the torch of life", beautifully expresses our dependence on those forerunners of Science whose work has benefited the world.

And in conclusion may I add --

"Like tides on a crescent sea beach,
When the Moon is new and thin,
Into the mind conceptions
Come welling and surging in;
Come from the distant ocean
Whose rim no foot nas trod,
Some call it Inspiration,
But others call it God."

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THE SYDNEY HARBOUR BRIDGE.

Specification and Tenders.

In this broadcast I will briefly review the Specification, Plans and Schedule of Quantities on which Tenders were called.

May I begin by quoting these lines written by James Allen --

"Mind is the Master power that moulds and makes,
And man is Mind, and evermore he takes
The Tool of Thought, and shaping what he wills,
Brings forth a thousand joys, a thousand ills:
He thinks in secret, and it comes to pass,
Environment is but his looking-glass."

From these Plans and Specification, Sydney's Bridge came into being.

The Specification contains 470 Clauses and is in fourteen parts.

Part 1, DESCRIPTIVE AND GENERAL, contains forty-one Clauses.

The first Clause reads --

"This Contract is to include the whole of the work required for the Manufacture, Supply and Delivery of all Metalwork, and the Construction and Erection complete and ready for traffic of a Cantilever Bridge or an Arch Bridge from Dawes' Point to Milson's Point, carrying four lines of railway, a roadway 57 feet wide between kerbs, and two footways each 10 feet wide, across Sydney Harbour, also the Approach Spans thereto, in accordance with this Specification, the Plans and General Conditions as set forth herein."

Clause 20 reads --

"The/

"The Contractor must satisfy himself as to the sufficiency and suitability of the designs, plans and specifications upon which the Bridge is to be built, as the Contractor will be required to guarantee the satisfactory erection and completion of the Bridge, and it is to be expressly understood that he undertakes the entire responsibility not only for the materials and construction of the Bridge, but also for the design, calculations, specifications and plans furnished to or by him, for the quantities submitted by him in his Tender as accurately representing the amount of work involved and for the sufficiency of the Bridge for the loads therein specified."

When the first Quebec Bridge fell into the St. Lawrence River, there was no Clause in the Contract by which the Contractors could be made to remove it, and the fallen bridge had to be removed by the Canadian Government. The Sydney Harbour Arch Bridge is very much larger than any arch bridge constructed, and to safeguard the State in case of failure, I inserted this provision in the Specification.

The "design, plans and specifications upon which the Bridge is to be built" are those embodied in this Specification, The Clause ensured that whoever obtained the Contract could not in case of accident disclaim responsibility for having accepted the design, plans and specification prepared by me, approved by Parliament and submitted for Tenders by the Government in 1923.

There is no legal loophole in the Clause, the Contractors had to accept the responsibility for the design of the Bridge

insofar/

insofar as its erection was involved. Should an accident have happened after having accepted the design as practicable, whoever obtained the Contract could not disclaim responsibility, but the Clause did not relieve me of any of my responsibilities.

Another Clause safeguarding the interests of the State reads --

> "It is understood that the Schedule Rates stated by the Contractor in his Tender shall be those upon which he agrees to be paid in Australian currency at Sydney, free of all transmission and conversion charges for the works covered by this Specification."

If payment had been made abroad as was desired by various prospective Tenderers, the State would have had to meet the heavy exchange charges caused by the financial crash which has for some years upset the finance of the world.

Part 2, PLANS, STRESS SHEETS AND QUANTITIES, contains twenty-six Clauses and enumerates the twenty-six Plans incorporated in the Specification.

Clause 43 gave Tenderers the latitude to alter details, but the salient features had to be observed, the span of the Arch of 1,650 feet, or its deck arrangement, could not be altered.

Clause 48 stated that complete working drawings were not

required/

required, but sufficient detail must be supplied to enable Tender to be checked.

Clause 49 reads --

> "The Tenderer shall submit plans showing clearly the method of erection and the travellers proposed, so that the erection stresses may be readily checked and the problems arising during erection may be fully considered."

Clause 56 made it obligatory for the Contractor to submit all erection plans, stress sheets and details incidental to the erection for the approval of the Chief Engineer, whilst Clause 57 states that --

> "The Contractor must prepare such Contract Working Drawings and Tracings required by the Chief Engineer for the superstructure and substructure, which shall forthwith become the property of the Minister, and no copy of any such Plan, other than those required for the carrying out of the Contract, shall be given to any person without the written consent of the Chief Engineer."

Clause 59 stipulated --

> "No Plan, Drawing, Stress Sheet, or other Document, shall be deemed to have been properly approved, until it has been signed by the Chief Engineer."

Part 3 specifies in forty-two Clauses, the MATERIALS OF CONSTRUCTION FOR THE SUPERSTRUCTURE.

The chemical and physical properties of Structural Carbon Steel, Silicon Steel, Nickel Steel, Chrome Nickel Steel and Chrome Nickel Molybdenum Steel, Steel Castings, Cast Iron, Bronze, and Gunmetal were set out in minute detail, and Tenderers were given the option of utilising one or more kinds of

steel/

steel in the make up of the details.

Part 4, in twenty-seven Clauses, stipulated the LOADING, dead, live, impact, wind, temperature, traction and erection loads to be provided for. They have been outlined in a previous broadcast.

Part 5, in twenty-five Clauses, fixed the UNIT STRESSES in all parts of the structure and defined how the details were to be proportioned.

Part 6, in thirty-four Clauses, fixed the DESIGN OF DETAILS, the first Clause stating --

> "Details shall be so designed that all parts will be accessible for inspection, cleaning, painting and repairs."

Part 7, WORKMANSHIP, the first Clause stated --

> "All parts of the work shall be built in accordance with the approved Plans and this Specification. The workmanship and finish shall be the best that the most suitable modern machinery and skilled labour to be obtained can produce."

and the manner in which the Bridge was to be fabricated was fully set out in the fifty-five Clause of this Part.

Part 8, in twenty-three Clauses, treated of the INSPECTION AND TESTING of the material.

Part 9 provided for a series of full-sized tests.

The Bridge was of unprecedented size, I had fixed the working stresses allowable, but as an additional safeguard, I specified that models of the truss members, of the maximum

size/

size which the testing machines specified could test should be made and tested to desctuction, so that I might determine if the unit stresses I had specified required to be amended.

Clause 280 reads --

> "For information and to finally review the allowable unit stresses on sections and details of truss members, test models of such members reduced in scale, also splices and other details, shall be tested by the Contractor under the direction of the Chief Engineer, and in accordance with the drawings to be furnished by the Chief Engineer and in such numbers as he may order.
>
> "The test models of truss members shall be of the maximum dimensions which the largest testing machine available will test, provided the capacity of the machine is satisfactory to the Chief Engineer. In tension members one leaf may represent the member."

On account of the unprecedented type and size of members of the Bridge, my Specification provided that for information and to finally review the allowable unit stresses which I had previously specified, models of members, reduced in scale, were to be tested in a machine of not less than 2,800,000 lbs. (1,250 tons) capacity.

The testing machine was made by Messrs. Avery and Company and will no doubt be availed of in England for any similar work. This machine is the largest "Universal" Testing Machine in the world. A compression member 50 feet long and 45 inches square can be tested to destruction with results accurate to one-quarter of a ton at full load. In tensile tests, solid

members/

members up to 6 inches in diameter can be employed, or flat bars up to 12" x 3".

The test results showed that no revision as to the type of member was necessary in any instance, and that the specified allowable working stresses were satisfactory.

The heaviest section of the lower chord was tested up to the limit of the machine producing a direct stress of 40,000 lbs. per square inch without sign of failure or distress in any part.

The lower chord members of lighter sections were crushed at 50,000 lbs. per square inch as against 16,350 lbs. per square inch, the working stress allowed.

The heavy top chord members failed by flexure at 51,000 lbs. per square inch, the lightest top chord member at 46,500 lbs. per square inch.

Part 10, in seventeen Clauses, dealt with SHIPPING AND ERECTION. It was stipulated that a complete agreement of the location of all parts of the Bridge had to be come to between the Contractor and the Chief Engineer before erection began.

Part 11, in thirty-five Clauses, specified the COMPOSITION OF THE PAINT AND THE METHOD OF MIXING.

Of the paint for the Bridge and the finishing colour, I made a study and found pure red lead and pure white lead and

oil/

oil best stood exposure and best protected the steel. The latest long span Bridge in America, the Philadelphia-Camden Bridge, si thus painted. The finishing coat being tinted to give the Bridge the desired shade.

The Quebec Bridge was similarly painted, the colouring matter used was chrome green oxide, which gave a fine, distinctive colour to the Bridge when newly painted.

In December, 1924, I visited Quebec especially to see how the paint had stood up to six years' exposure. Where the paint was not directly exposed to the elements, coloured by the chrome green oxide, it still looked well, but Phoebe's "yellow, bilious, jaundiced jealousy" over a pseudo Yeoman of the Guard, had nothing on the streaky colour of that paint where wind-whipped by rain and snow, and directly exposed to the sun.

Clause 325 stated --

> "To enable the final tint of the finishing colour to be determined, the Contractor will be required to prepare and maintain in suitable locations steel plates not exceeding ten in number, about 6 feet square, or such other size as may be directed, and to paint same with paints of the composition and tints directed by the Chief Engineer. These metal sheets must be maintained in such place or places as directed during the currency of the Contract."

These steel plates were erected at Dawes' Point, and after four years' exposure, the most suitable tint proved to be a paint composed of pure white lead in pure linseed oil coloured light grey with a small addition of vegetable black. It

had/

had not faded or deteriorated, whereas the other sample paints and tints had.

Part 12, in ninety Clauses, specified the Cement, Sand, Concrete Metal, Grout, Mortar, the various Classes of Concrete and Granite Masonry, the Asphalt, Ruberoid and the Timber to be used in accordance with the design shown by the Plans.

Part 13, in nine Clauses, described the FOUNDATIONS and the diamond drill bores which had been taken by me previous to tenders being called and the bores which the Contractors had to take as part of the construction to enable me to determine the depth of foundations of the main piers.

Part 14, in thirty-nine Clauses, described in detail the PIERS, ABUTMENT TOWERS AND PYLONS OF THE BRIDGE, whilst the Plans embodied in the Specification fixed the dimensions and details.

The Schedule of Quantities in twenty-eight items gave the detail quantities on which the tenders were called, except the steelwork quantities. These for a Bridge constructed in carbon steel and nickel steel were given to each tenderer by me some time before their tenders were submitted.

World-wide tenders were called by the then Minister for Public Works, Mr. Ball, on the Specification and Plans signed by me on January 31st, 1923, calling for Tenders for a

Cantilever/

Cantilever Bridge of 1,600 feet span and a two-hinged spandrel braced Arch Bridge of 1,650 feet span with abutment towers and pylons. Competitive designs were not called.

On January 16th, 1924, tenders were opened in the Minister's room. Six firms submitted twenty tenders, viz.,

Sir Wm. Arrol & Co., Glasgow	... ...	Two tenders.
Dorman, Long & Co., Ltd.,	... ...	Seven "
Canadian Bridge Co.,	... ...	Two "
McClintic Marshall Products Co.,	...	Five "
English Electric Co. of Australia	...	Three "
The Goninan Bridge Corporation	...	One tender.

Contrary to the terms of the invitation for tenders, which was for a Cantilever Bridge or an Arch Bridge with abutment towers and pylons, tenders were sent in for the construction of Suspension Bridges, Cantilever-Arch Bridges, or Cantilever-Suspension Bridges. These tenders were given impartial consideration, but none of them were as satisfactory as the designs submitted for tenders. Sir Wm. Arrol & Co. submitted two tenders, one for the construction of the Cantilever, the other for the Arch Bridge, in strict conformity with the Specification, stating --

> "We can suggest nothing better than Mr. Bradfield has put before us."

Dorman, Long & Co., Ltd., submitted seven tenders, two for Cantilever Bridges, three for Arch Bridges, one in accordance with the official design, one of which did not include abutment towers, the third for an Arch Bridge with abutment towers designed by Sir John Burnet & Partners, also two tenders for Cantilever-Arch Bridges, one with, and one without, abutment towers. Alternative tenders were also submitted by Dorman, Long & Co., Ltd., for facing the piers with precast concrete blocks instead of granite.

My estimate for the Arch Bridge, with abutment towers as submitted for tenders, was £4,339,530; Sir Wm. Arrol's tender was £4,655,351; Dorman, Long's tender was £4,217,721. There was a difference between the two lowest Tenderers of £438,000, in favour of Dorman, Long & Co., Ltd. After investigating the two tenders from every angle, and satisfying myself that by the erection scheme proposed, the Arch could be successfully erected, I recommended the tender of Dorman, Long & Co., Ltd., for the Arch Bridge with abutment towers and pylons.

All tenders were based on the rates of wages and hours of labour prevailing in New South Wales on the day tenders closed. Any alterations made by a Federal or State Court or by an Industrial Agreement involving an increase or decrease were to be added to or deducted from the Contract. On the Bridge and

Approaches these variations have added over £700,000 to the cost of the Bridge.

In concluding my Report on Tenders, dated February 16th, 1924, I stated --

"The tender recommended, for the two-hinged Arch Bridge, with granite masonry facing, is my design as sanctioned by Parliament and as submitted for tenders.

"In making my recommendation I have kept in view the past and future as well as the present. One characteristic of modern thought is the increasing tendency to study the past, and in looking backward we find a nation's manner of life a civilisation written in those works of its rulers which have survived the ravages of time.

"In the upbuilding of any nation the land slowly moulds the people, the people with patient toil alter the face of the landscape; clearing forests, draining swamps, tilling fields, constructing roads and railways, building factories and rearing cities, they humanise the landscape after their own image. Thus in the years to come will result the perfected product, land and people, body and soul, bound together by innumerable and subtle ties.

"Future generations will judge our generation by our works. For that reason and from considerations of the past, I have recommended granite, strong, imperishable, a natural product, rather than a cheaper artificial material, for the facing of the piers, although the cost is £240,000 greater; humanising our landscape in simplicity, strength and sincerity."

Characteristics of the true Australians of our generation.

After the acceptance of the tender was announced, "Engineering", London, to which paper I had sent a copy of my report on tenders, published the following criticism:-

"De gustibus non est disputandum' is an ancient and

generally/

generally acceptable adage, but the maxim is not one for all times and seasons. There are occasions when it is not only legitimate, but highly desirable, that matters of taste should be debated. Questions of this kind are bound to arise when works are to be undertaken which will serve not merely the present, but probably many, succeeding generations. Our own self-respect is involved in this, since scientifically and mechanically our successors are bound to be our superiors, but in the realm of art there is no reason why we should not equal the best to be accomplished by even the most remote of our descendants. It is thus most desirable that when monumental structures are to be erected, aesthetic considerations should be thoroughly considered, and it is no longer allowable to dismiss inartistic proposals with the trite, but often untrue, observation that argument on matters of taste is impossible.

"In our last issue we gave particulars of the various proposals made for the great Bridge across Sydney Harbour. This will have a span of 1,650 feet, and the structure ought to embody not merely the best of which the present generation is capable in the way of structural engineering, but ought also to be a premanent monument to our good taste. Those who have studied the designs submitted must have been struck by the fact that practically the same designs were submitted by more than one of the tenderers. The explanation lies in the fact that these reproduce in essentials the 'official designs', which were issued at the same time as the Specifications. Quite naturally the successful tenderer included also proposals for structures differing aesthetically from that selected by Mr. J. J. C. Bradfield, M.Inst.C.E., the Chief Engineer, who perhaps, was swayed subconsciously by some sort of paternal affection for the official designs.

"Mr. Bradfield's report is excellent on the technical side, but we find ourselves in disagreement with many of his observations on the artistic merits of the various designs submitted. Naturally, this is a matter of taste, and we do not propose to assert that our own views are superior to Mr. Bradfield's, but there do appear to be certain features in the recommended design, as to which reasoned criticism is possible.

"It is/

"It is recognised maxim in all structural design that function should govern form and not vice versa. Now, the form selected for the arch is that appropriate to the type which is fixed at the abutments, and not that characteristic of a two-hinged structure. The educated observed viewing the Bridge from a distance would quite naturally conclude that the arch was fixed at the springings and would then be pained by the obvious inadequacy of the towers shown, to withstand such strains as might be imposed by an arch of this 'rigid' type. The towers look as if they would be overturned, since in a rigid arch the line of resultant thrust would be situated far above the level of the hinge actually used.

"As already indicated, however, appearances are in this instance deceptive, and the arch is really a two-hinged one, but we think it can hardly be denied that it is an artistic error to give it a misleading outline."

This criticism was, and still is, incomprehensible to me; the thrust from the arch can only be transferred into the abutments through the lower chord, as the design clearly shows, and if anyone is pained by the obvious inadequacy of the towers shown, which, according to "Engineering", "look as if they would be overturned", in my opinion, they get pains quite easily.

The article reads on --

"There is, however, in our opinion, another aesthetic fault embodied in the official design. 'Even a joke should have a meaning', observed the Red Queen to Alice in her looking-glass Adventures, and we may paraphrase Her Majesty's concluding word by asserting 'that a tower is more important than a joke.' It would, however, require an ingenuity rivalling in quality that of the White Knight to find any meaning for the two enormous and expensive towers embodied in the accepted design. The towers, in fact, have no structural significance whatever. They are merely enormous aggregations of

granite/

granite and concrete, forming no integral part of the structure, and put in merely with a view to 'architectural effect.' Architects, however, are not good guides in the matter of steelwork design. As the history of building shows, the architects of each age in which structural materials have changed have invariably long adhered to traditions inherited from the prior state of the constructional arts, and reproduced, say, in stone, features and details, which arose naturally and quite appropriately in the previous use, perhaps, of timber. In regard to steel bridges, the architect has not yet learnt to discard traditions inherited from the "Stone Age', and in fact has had little opportunity of doing so, since it is his practice to transfer to the Engineer the design of all steelwork which presents any special difficulty. 'Lie heavy on him, earth, for he laid many a heavy load on thee', was the epitaph suggested for Vanbrugh, and the subsoil of Sydney Harbour might well echo the sentiment so far as this mass of meaningless masonry is concerned."

To which I replied --

"In your issue of August 1st, 1924, your paper in an Editorial dealt with the Sydney Harbour Bridge Tenders and my report thereon, from which I gathered my report was considered eminently judicial -- which I might perhaps take as a compliment, I was subconsciously swayed in favour of my own design -- I am human, that my aesthetic sense was at least doubtful -- query -- and I was somewhat bold in my statements -- I had the courage to express my opinion.

"The photographs enclosed show a portion of the completed work which I am constructing from Redfern to Bay Road -- a City Railway and Bridge -- which I hope will not only be of great utility to and an adornment of this beautiful City, but also rank amongst the world's engineering achievements.

"Suppose you again conjure up the Red Queen, show her the photographs I have sent, and if her inspiration to your leader writer is that my taste still is crude and my ornamentation more than a joke, the White Knight might perhaps be induced to write another critique thereon.

"Please/

"Please do not think that I am writing this in an offensive spirit, it is vanity I suppose on my part, but I really thought and still think that I am not only building a useful but a beautiful City Railway and Bridge. When the Bridge is completed, the pylons will be an adornment to what would otherwise have been a strictly utilitarian steel structure not in keeping with its setting.

"'De gustibus non est disputandum', notwithstanding, we will then learn whether the Citizens of Sydney and world travellers agree with your criticism of my artistic sense, but probably the Editor of "Engineering" himself may have thought by that time that 'Aliquando bonus dormitat Homerus' (Sometimes the good Homer nods)."

To which the Editor of "Engineering" replied --

"I am glad to note that you have taken the remarks in our issue of the 1st August, 1924, in such very good part, and, as questions of taste can, I am afraid, only lead to endless discussion, I will content myself at the present moment by saying that the actually executed over-ground works illustrated in some of the photographs you have sent are certainly of most excellent appearance. Work of this kind has, I fear, not always been done too well in this country, and your street works certainly form an example which I should like to see thoroughly studied and digested elsewhere."

Then in my next letter, I wrote --

"Your paper criticised, somewhat caustically, my design, without having full knowledge of the facts and these I propose to give in the information I send you without making any reference whatever to your article of 1st August, 1924.

"Your paper was fair enough to state in that article that you did not propose to assert that your views were superior to mine, however, I have been, am being, and will I expect be subject to adverse criticism in that portion only of your article being quoted in the Sydney press, to the effect that the towers are a joke, meaningless, useless and waste of money, etc.

"We/

"We will not argue, but just state facts and quite frankly we will both know in time what the world thinks of those towers of mine which, according to 'Engineering' 'are more than a joke'.

"'Eile mit Weile' -- 'Make haste slowly' has been my way in life and perhaps in time I may be able to convert the inartistic soul of 'Engineering'."

His reply was --

"You will, I think, not expect me to write further about the general appearance of the Bridge, but I must confess that the effect produced in the general view of the completed structure which you send is certainly very fine, and I cannot think that that it will, in general, be likely to result in anything but praise."

Imagine the Bridge without the abutment towers, and see the Bridge as it now is, as it will be in the near future with the abutment towers and pylons floodlighted.

If the Bridge without the towers could have been erected, it would have been useful, but not elegant, the Bridge as it now is, is elegant and a more useful Bridge than without the abutment towers, these can be used for a variety of purposes. Below deck level, cold storage, theatre or restaurant, whilst at the balcony level, excellent views are obtained away from the lane of traffic, as also from the pylon tops, the acropolis of Sydney, from which the view is superb.

Standing on the highest floor now erected, some 40 feet below the top, from the southern pylons the ocean is visible

through/

through the Heads and the Gap, whilst from the northern pylons the vast Pacific, its blue rollers like ripples, blends itself dim and blue in the horizon about 20 miles away. From all the pylons the view is superb.

My awful pylons, according to "Engineering", meaningless masses of masonry, will be the show place of Sydney and the pride of her citizens.

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THE SYDNEY HARBOUR BRIDGE.

Northern Approach -- Turning of the First Sod.

As previously related, in 1922 I visited the most important bridge fabricating establishments throughout the world to answer any questions and give further particulars to intending Tenderers. Although a document under the seal of the State signed by the then Premier stated that such was my mission, I was told quite candidly that though the firms had no doubt as to my own bona fides and sincerity, they very much doubted if the Government really intended to construct the Bridge.

I reported to the Minister as under:-

"The principal bridge building firms in America, Great Britain and Europe were well aware that the Act authorising the construction of the Bridge had not received the sanction of Parliament. Paragraphs appearing in the Sydney daily press relative to the Bridge were evidently cabled to various firms, who were aware much earlier than I of the news current in Sydney. This news had an adverse and disquieting effect on Tenderers, I was told quite candidly that firms doubted the good faith of New South Wales in this matter, or that the work would be gone on with, and should tenders be received the Government had no authority to accept one. Moreover, tenders had been called twenty years ago under similar conditions, none of which, though satisfactory, had been accepted, nor were firms recompensed in any way, and they were not prepared again to go to the expense of preparing tenders running into thousands of pounds until the necessary legislative action had been completed, and the acceptance of a tender placed as far as possible outside the political arena.

"In the United States and Canada, three firms whose tenders were then well in course of preparation, were pre-

pared to/

pared to submit them, with the reservation that if a tender was not accepted, their Plans and Schedule of Prices should be treated as strictly confidential and not made public, whilst a fourth firm, the one largely interested in the tender which received second place some twenty years ago, on account of the uncertainty prevailing was not prepared to tender.

"In Great Britain, I was frankly told that until the Enabling Act as passed, none of the firms were prepared to go to the expense of tendering, this atitude also had its reflex on Continental firms, several of whom are endeavouring to make arrangements to submit a tender in conjunction with British firms.

"When I fully realised the situation, I advised the Acting Agent General to cable to the Premier recommending that the time for the closing of tenders should be extended so that the Enabling Act could be passed. If the Enabling Act is not passed, tenders should be withdrawn. If the Act is passed, an assurance by the Premier that the work will be gone on with, provided a satisfactory tender is received, will allay the existing mistrust, and on such an assurance, British, Canadian, United States and European firms are prepared to submit tenders.

"I would emphasise the fact that the problem of manufacturing and fabricating the steelwork for the Sydney Harbour Bridge is not only difficult, but most intricate, whilst its erection involves many problems requiring the highest Engineering skill in their solution, and it is only on account of the dearth of work prevailing throughout the world which will induce firms to tender.

"To allay the mistrust which exists, that New South Wales is no altogether in earnest in calling tenders, and to bring tenders to a satisfactory conclusion, I recommend that action be taken as follows:-

"(a) An announcement should be made by the Premier as Head of the Government that if a suitable tender is received it will be accepted. Such announcement will satisfy tenderers as to the good faith of New South Wales in calling for tenders.

"(b) Alternative/

"(b) Alternative tenders should not be called asking firms to submit proposals for constructing the Bridge without any cost to the State, and in payment therefor to have the right to collect tolls from traffic crossing the Bridge for a period of years.

"(c) That tenders should stand as now called for, i.e., payment to be made in current coin of the realm as the work proceeds."

The act containing these provisions was passed and received the Governor's assent on November 24th, 1922, which somewhat allayed the mistrust in the minds of intending Tenderers, who sent representatives to Sydney or had agents here, but the mistrust was still frequently voiced. To set aside all doubt, I made a submission to Mr. Ball, the then Minister for Works, asking for approval to begin the construction of the railway approach from Bay Road Station to the site of North Sydney Station, so that the railway goods traffic could be removed from Milson's Point, and the land at Milson's Point made available for the construction of the Bridge immediately a tender was accepted.

In making this recommendation nearly a year before tenders were due, I made one heap of thirty years previous service and risked it on a suitable tender being received. If tenders had not turned out as I had advised and in accordance with my estimates, there is no doubt my official life would have come to a sudden termination.

Mr. Ball, as Minister for Public Works, had to say, "Yea"

or/

or "Nay", and after verious discussions, he approved of work being commenced so as to divert the railway goods traffic from Milson's Point to where North Sydney Station is being built. The step was far-reaching, it indicated that the State was in earnest.

Alderman G. T. Clarke, once Lord Mayor of the City, was then Mayor of North Sydney, was a man of vision. He and I discussed the position. We recognised the decision to commence work might not be carried into effect, there might be a slip between the cup and the lip which a public function would render well nigh impossible. We knew that Parliament and Aldermen present would speak in favour of construction of the Bridge; speeches (twenty-four were made) would be published abroad and that the turning of the first sod would be an outward and visible sign of the bona fides of the State. Hence the Ceremony of Turning the First Sod.

Ald. Clarke, as Mayor of North Sydney, proposed to the other Minicipalities on the Northern side of the Harbour that a Ceremony should take place at the site of North Sydney Station, when the First Sod of the Northern Railway Approach was turned there. The Councils concurred and jointly arranged the ceremony.

In the souvenir issued on the occasion, it was stated --

"To suitably celebrate the commencement of the construction of the Northern Railway Approach to the Bridge, the

Mayors/

Mayors and Presidents of the Municipalities and Shires on the northern side of the Harbour have requested the Hon. R. T. Ball, M.L.A., Minister for Public Works and Railways, to perform the ceremony of turning the first sod at the site of the North Sydney Station on 28th July, 1923.

"The function will take place at a spot which commands a splendid view of that portion of the Harbour to be spanned by the future Bridge and those attending the ceremony will be able to form a fair idea of the benefits that will be derived by the present and future generations from the foresight of the Designer and the enterprise and pertinacity of all who have contributed to secure legislative sanction for this great work. To all such it will remain an imperishable monument."

Thus the third hurdle was successfully negotiated -- the first, whether the linking of Sydney with the Northern Suburbs was to be by Bridge or Subway; the second, the Passing of an Enabling Act after three previous submissions to Parliament had failed; the third, the commencement of work prior to tenders being received, a visible sign of the sincerity of the State.

July 28th, 1923, was the first red-letter day in the construction of the Bridge, and a brief resumé of the speeches on that day may be of interest.

The souvenir states --

"The Ceremony of Turning the First Sod of the Northern Railway Approach to the Sydney Harbour Bridge took place on Saturday afternoon, 28th July, 1923, amidst every sign of popular interest and enthusiasm, which intermittent rain showers could not diminish.

"Long before the time for the commencement of the ceremony (3 o'clock) the people flocked to the spot at

the/

the corner of Miller and Blue Streets, to secure vantage-ground. By the time the proceedings were to start, there were several thousands of the public present."

"Ald. G. T. Clarke (Mayor of North Sydney) presided; on the immediate right and left of him were Sir George Fuller, K.C.M.G., the Hon. R. T. Ball, M.L.A. (Minister for Public Works), and Mr. J. J. C. Bradfield (Designer of the Bridge).

"The Mayor, who was received with loud applause, said:-

"'I have the honour of presiding at this celebration -- a prelude to one of the greatest events about to take place in modern history -- the construction of the Sydney Harbour Bridge.

"'When completed, I venture to say that our Bridge will be classed alongside similar undertakings in the world, designed by an Australian Engineer, who is engaged to see the work to completion. I do not intend going into a description of the Bridge, or giving you figures concerning the same, you will get that information from the souvenir issued, besides you will hear so many speeches during the day bearing on the Bridge by those capable of dealing with the question, that I shall confine my remarks briefly to the potentialities of the Bridge bearing on the future. We have a population of about one million in the Metropolitan Area of Sydney, one of the largest Cities in the British Empire, it is still growing, and when our children's children take our place, I venture to say that Sydney will be a competitor with other Cities who are our seniors in point of age and population. It is with the help of such enterprises as those we are now engaged in that we are going to make our City, State and Commonwealth, great and progressive. The Bridge will foster commerce, convenience and utility, and from the figures supplied, after a few years, will be a self-supporting undertaking; the ratepayers of the City and the Northern Suburbs are nobly responding to the call to pay their proportion of the cost; why not the whole of the ratepayers of the Metropolitan Area and the people of the State, they will all benefit -- it is a National work, the same as the Country Railways, river and other bridges built and maintained out of the revenue received from the whole State. The direct route to Queensland, the Northern towns and districts of New South Wales

will be via the Bridge, our northern shores will be requisitioned for shipping, then our manufactures and other commercial pursuits will follow, to say nothing of the opening up of large areas of residential lands, which are properly described as the highlands of Sydney. We, who reside on this, the Northern side of the Harbour, welcome our guests; we are proud of the opportunity to be the first to celebrate the occasion, which adds another chapter in the books of important events in Australian history. I say, in conclusion, that the Sydney Harbour Bridge, when completed, will be one of the greatest undertakings ever achieved in Australia. To you, Sir George, Mr. Ball and the Members of Parliament, who have done trojan service to the present and future generations, we owe much, also to those men who preceded you in the past -- Sir Henry Parkes, E. W. O'Sullivan, the Hon. J. Estell, J. H. Cann, Sir Thomas Henley, Sir Joseph Carruthers, and others who have held office in previous Governments, not forgetting those local men who for forty years have been fighting for the cause, many of whom have been taken from us, but their great help remains green in our memory. Ladies and gentlemen, I thank you for your attendance today, take a hopeful view of the future, do not look on the dark side of things. The immediate construction of the Bridge is assured; the Ministry, a majority of Members of Parliament, and the people are behind it, it must go on, the end crowns the work."

"THE PREMIER'S ADDRESS.

"Sir George Fuller said that it was a source of great pleasure on his return from abroad to make his first public appearance in New South Wales on that great historic occasion. He remembered Sir Henry Parkes inviting the people of North Sydney to stand by his side and build the Bridge. It had, however, remained for the Government, of which he was the head, to bring that great National work to its present position.

"'Today, the Harbour Bridge Act is a law of the land', said the Premier, 'and you have a Ministry in power which is determined to have it carried out in the interests, not only of Sydney, but of New South Wales at large'.

"When visiting the Quebec Bridge recently, Sir George added he had been told by Mr. Porter, the Designer, that

Mr. Bradfield/

Mr. Bradfield had climbed to a great height on that Bridge, in a howling storm, in order to test the vibration by a passing train. That showed his thoroughness. Mr. Bradfield had devoted himself to a great research so that they might have a Bridge of the greatest stability."

"TURNING THE SOD.

"Prior to turning the sod, Mr. Ball outlined the various Bridge projects and their vicissitudes, beginning with Greenaway's suggestion in 1815. The matter had been before Parliament on four occasions. The Bill had a rough passage, but, with the assistance of the Members for the district and others, they had got it through the Assembly and Council. Mr. Ball paid a tribute to Sir Joseph Carruthers for his capable direction of the measure to a haven of safety. It was the intention of the Government to finish the job. A gang of men would start at 8.30 on Monday morning. Tenders would be received on 30th November, so it was necessary to make provision for the Approach on that side of the Harbour. Their Engineer had told them there was likely to be keen competition for the Bridge Contract.

"Continuing, Mr. Ball said that they were associated with one of the biggest public works ever completed in the Commonwealth. It was by far the largest National work, and in some respects it was to be the biggest Bridge in the world. It had been designed to carry four electric trains at one time, together with all the traffic the road and passenger ways could accommodate. It had been designed on up-to-date lines by an Australian Engineer to meet requirements for many years ahead. Mr. Bradfield had been termed a visionary, but that was the kind of Engineer they wanted.

"The people of the Northern Suburbs and of portion of the City were to contribute one-third of the cost, Mr. Ball added, and the remainder would be provided by the Railway Commissioners.

"Mr. Ball, after being presented with a spade suitably inscribed and be-ribboned, descended the platform to the spot where the sod was to be turned. He dug the spade into the earth amidst tumultuous applause of the onlookers, while the band followed with Australia's National Anthem,

"Advance/

'Advance Australia Fair', all present joining in the singing with great fervour and enthusiasm."

The second red-letter day was on March 26th, 1925, one year and eight months after the work had been begun. During this interval, tenders had been received and finalised, and the Tender of Dorman, Long & Co., Ltd., accepted.

His Excellency Sir Dudley de Chair presided, the foundation stone was laid by Mr. Ball, Minister for Public Works. Sir Arthur Dorman and Sir Hugh Bell, Directors of the Contracting Firm, journeyed from England for the ceremony.

Sir Hugh was a unique personality. Sir Arthur told me that Sir Hugh was the talking partner and made the speeches. One of his stories was that a lady well-known to him had married a Mahommedan. They did not see eye to eye with each other and the husband told his head man that when Madam died, she was to be buried as far away as possible from where he was buried if he died first. It was part of his religious belief that the first lady he saw on the Resurrection morn he would have to journey through Paradise with, and he wasn't taking any risks.

Sir Hugh's speech was acclaimed to be the outstanding speech.

"I have been engaged in the manufacture of iron for 63 years, and I BEGIN TO KNOW HOW LITTLE I KNOW ABOUT IT!

"We do not under-estimate the difficulties of this work. To Dr. Bradfield, the designer of the Bridge, I give every credit. His capacity and ability have impressed me very deeply. We have had the opportunity of finding out the character of the man we have to deal with. While I expect no mercy from him, I expect that we shall get full justice.

"Dr. Bradfield prepared alternative plans for the Bridge, one providing for a Cantilever, and the other for an Arch Bridge. This Arch will be a stupendous work. The Eiffel Tower was not a patch upon the great Forth Bridge, built in 1890. It is easy to build a tower, putting brick upon brick, but the Forth Bridge was an Engineering undertaking of stupendous difficulty. At that time, however, it would have been impossible to erect <u>such a Bridge as is begun today</u>.

"Only recently could such a work have been accomplished. Dr. Bradfield wisely offered the Cantilever and the Arch as alternatives. We submitted tenders on both lines. This is the largest span of arch in the world, and has to be constructed, as the bridge of Ctesiphon was, without any centre support. It was in order that he might study the conditions under which we propose to construct that arch that Dr. Bradfield came to England. Pictures of the Bridge in various stages of construction are exhibited on the walls of the hall where refreshments will be served, and visitors are invited to inspect them.

"The Bridge as it grows out towards the centre of the arch, will be tied back by enormous ropes, which will stand a strain of 1,200 tons.

"The two members of the arch when they meet in the middle will be exactly opposite each other. If they should be as much as 5 inches out, Mr. Ennis, our Engineer, will be bitterly disappointed, and Dr. Bradfield will be furiously angry. I should like to pay a tribute to our Supervising Engineer, Mr. Ennis, and to say how deeply we feel indebted to him and to his Staff.

"We count upon the loyal co-operation of the Australian workman. We have no fault to find with him, and we hope that when the work is completed, no feeling of irritation or dissatisfaction will be left on either side.

"The prosperity of all makes the prosperity of each.

If/

If you in Australia prosper, you are making for our prosperity in England. I acknowledge the obligation we are under to Dr. Bradfield and his Staff. Without his help and counsel we could not have come to so satisfactory an issue. And I am glad to acknowledge the great obligation we are under.

"But words are mere words, and are speedily forgotten. We would like to place in Dr. Bradfield's hands a more permanent memento of our pleasant relations in this work. And so, Dr. Bradfield, I ask you to accept a copy of the silver casket which we have presented to your Chief, Hon. R. T. Ball."

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THE SYDNEY HARBOUR BRIDGE.

Dorman, Long & Company's Tender and the Finalisation of Plans.

As submitted for tenders, the Arch had 33 panels of 50 feet and sprang from its bearings at level 40.00 feet above mean sea level, the rise, that is, the distance from the centre of bearings to the centre of the lower chord of the Arch at the centre of the Bridge, was 370 feet, the abutment towers were each 117 feet wide, the end approach span on the Sydney side was 244 feet long, of sufficient span to clear York Street and George Street North. Where the deck passed through the Arch there was no difficulty as this detail had been fully investigated by me when fixing the rise and the number of panels in the arch.

In the tender, as accepted, the arch had 28 panels of approximately 59 feet each. It sprang from its bearings at level 38.00 feet above mean sea level, rise of arch 350 feet, the abutment towers above ground were as shown by the Official Plans, 117 feet wide, with five approach spans on each side, the end approach span on the south side was 195 feet span, and was not of sufficient length to span York Street and George Street North.

Ten drawings were submitted with the tender, also some

calculation sheets which showed the proposed make-up of the various sections in sketch form, sufficient information for checking the tender.

In reporting on tenders, I stated --

> "The calculations submitted with tenders are of the highest order of perfection, thoroughness, and detail. Messrs. Dorman, Long & Co., have supplied full and accurate details of secondary stresses, which have been investigated on approved lines.
>
> "Associated as Architects with Dorman, Long & Co., is the eminent firm of Sir John Burnet and Partners, and as Engineers, Mr. R. Freeman, M.Inst.C.E., M.Am.Soc.C.E., of Sir Douglas Fox and Partners, and Mr. G. Imbault, formerly Chief Engineer of the Cleveland Bridge and Engineering Company, of Darlington, England."

Complete working drawings were not submitted for tenders, nor were they required from Tenderers, the Specification providing that the successful Tenderer should make these working drawings subject to my check and approval.

In submitting their tender, Dorman, Long & Company stated --

> "It is thought that, in connection with an undertaking of this magnitude, difficulties may arise as to the correct methods of calculation or details of design, and, in order to ensure absolute reliability of the Bridge, that provision should be made for reference on such points to arbitration."

The Minister would not agree to this provision, he insisted that my decision, as Chief Engineer, was to be final, as was specified.

The provision had to be withdrawn and with the full knowledge that I was the sole arbiter on all technical matters, Dorman, Long & Co., signed the Contract on March 24th, 1924.

In September, 1924, I arrived in London, preceded by a small Staff of Australian Engineering Graduates for the purpose of finalising the Plans, and investigating the machinery and methods proposed by the Contractors for the fabrication and erection of the Bridge.

GENERAL DESIGN:

The general design of the structure had to be reviewed, as, prior to my arrival in London, the Contractors had found that with the layout of the main span having 28 panels of nearly 59 feet span and rise of 350 feet, the level of the deck in relationship to the main arch trusses precluded the development of a satisfactory detail at the point where the deck passed through the lower chords of the arch. I investigated four schemes and decided that the most satisfactory solution of the difficulty would be to lower the arch trusses relative to the deck by 10 feet 6 inches so that the cross-girder at this point, where the deck passes through the arch, could be taken above the chord gusset plates. It necessitated the special type of cross-girder as now erected.

The lowering of the arch relative to the deck brought the springing of the arch very near to the surface of the

ground which seriously detracted from the appearance of the Bridge and abutment towers. I developed the outline of abutment towers as now built reducing the height of the pylons by 25 feet and battering the face adjacent to the main span to offset the squat appearance caused by the lowering of the arch. This battering increased the width of the abutment towers from 117 feet to 150 feet, i.e., by 33 feet, and brought into being the space now apparent between the end steel verticals of the arch and the face of the pylon. In discussing this feature with Sir John Burnet in London, he advised that as the battered face of the pylon and the slope of the end diagonal of the arch were similar, there was no objection.

The length of steelwork as submitted for tenders was 3,770 feet, so the length of each of the five approach spans on either side of the abutment towers had to be reduced on account of this increase in width of the abutment towers, whilst to clear George Street and York Street, the end approach span was increased in length from 195 feet (in tender) to 238 feet span. This, I knew, would have to be done when recommending the tender for acceptance; and so came into being the outline of the Bridge now constructed across the Harbour.

A Plan of this revised elevation was sent by me to the Contractors on October 29th, 1924, with a letter instructing them that it was to be adopted. The Contractors acknowledged

receipt/

receipt on November 7th, 1924, as under:-

"We beg to acknowledge receipt of and thank you for the additional six copies of the Plan No. 1, General Elevation dated 20th October, 1924. We much appreciate your kindness in letting us have these additional copies, which we will find of considerable assistance to us and our Consulting Engineers."

Again on November 10th, 1924 --

"We have to acknowledge receipt of, and thank you for 3 copies of approved Plan No. 1, "General Elevation", dated 20th October, 1924. The plan embodies the latest approved general design."

In discussions with Mr. Ennis as to the make-up of Main Arch members, I was given to understand that his firm might be prepared to roll a larger angle than the 10" x10" angle, tendered for, and, on September 18th, 1924, I wrote to Dorman, Long & Co., as follows:-

"As submitted with your Tender the make-up of the lower chords of the Main Arch spans consists of twelve flange angles 10" x 10" x 1¼", upper and lower flange plates 10 feet 10 inches wide in four pieces, three smaller flange splice plates in each chord, four web plates and four web reinforcing plates.

"I am of the opinion that a better balanced and more efficient section can be obtained by increasing the size of the flange angles to a maximum of 12" x 12" x 1¼", if such angles can be satisfactorily produced and if your firm is prepared to supply them without increase in cost. Further, to make provision for the gusset plates at each joint, a flat 12" x 1½" might be incorporated in each flange in such a position as to be readily displaced by a gusset plate of similar thickness, and each upper and lower flange plate instead of consisting each of four pieces with three outside longitudinal splice plates, should preferably be in two pieces with one central

longitudinal/

longitudinal splice having inside and outside covers. This arrangement would reduce the number of longitudinal splices from three to one in each flange, and there will be equal facility for erection as presumably it is your intention to erect the chord in two similar longitudinal halves.

"Please submit drawings of typical members of the lower chord showing the original cross-sections furnished with your Tender and the cross-sections suggested as above, giving areas, moments of inertia and bending stress due to weight of members.

"It is distinctly understood that if the proposed section is adopted, there is to be no increase whatever in the Contract price on account of either the manufacture, fabrication or erection of the steelwork or any variation whatever in your Firm's obligations and responsibility under the terms of Specification and Contract documents."

A reply was received from the Contractors on September 24th, as follows:-

"We duly received your letter of September 18th with reference to the make-up of the main arch at bottom chords, and we note you consider that a better balanced and more efficient section can be obtained by increasing the size of the main flange angles to 12" x 12" x 1¼"

"We have taken this matter up with our Rolling Mills, and they have agreed that 12" x 12" angles of the gauges required, can be satisfactorily rolled in our Britannia Mills, and should these angles be supplied by Dorman, Long & Co., from their Rolling Mills, no extra to you will be incurred.

"We are communicating the contents of your letter under reply to our Consulting Engineers, Messrs. Sir Douglas Fox & Partners & G. C. Imbault, requesting them to submit drawings of typical members of the lower chord showing the original cross-sections furnished with our tender, and the cross-sections as suggested above, giving areas, moments of inertia and bending stress due to weight of members."

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The following letter, dated September 26th, 1924, was received through the Contractors from Mr. Ralph Freeman, on behalf of Sir Douglas Fox & Partners and Mr. G. C. Imbault:-

"We send you herewith two copies of each of the two drawings as requested by you in your letter of the 18th inst., Nos. A2/F65 and A2/F66."

Another matter of importance in the make-up of the main arch members was the question of over-run.

In the rolling of large plates and sections, the rolls may spring or wear and so increase the nominal thickness of the plate or section. For example, a plate weighing 100 lbs. per sq. foot could, on account of the causes above, weigh 103 lbs. per sq. foot, or more, and under the terms of the Specification this excess weight, called the over-run, would have had to be paid for up to 2% of the nominal weight of the plate or section. The extra material was of no advantage to the Bridge, adding unnecessary weight, and to offset the possibility of over-run in the steel plates, I asked the Contractors to reduce the nominal thickness of the plates by 1% when rolling. The Contractors agreed to do this and submitted a scheme for the purpose, by which the edge thickness of all silicon steel plates was to be reduced by 1/100 inch as rolled. In agreeing to do this, the probability of an extra on the Contract on account of over-run was rendered negligible, the additional steel would have cost

tendered for.

The details of deck were most carefully reviewed, and on September 15th, 1924, I notified the Contractors that the troughing on the roadways and footways was to be extended to form the kerbing on either side, asked them to prepare a drawing of the cross-section of the trough plate, instructed that plate-web stringers were to be placed under the roadway parapets instead of making the parapet itself carry the loading from the deck, as in their tender, and thus brought the detail back to that shown in the Specification. I increased the thickness of the roadway concrete above the troughing from 3 inches to 4 inches, and instructed that the 1 inch of concrete above the footway troughing was to be omitted. On October 13th, 1924, I wrote fixing these and all other details of the deck.

On my return to Sydney in January, 1925, I forwarded my Report on the finalisation of Plans and Mr. Cooper, in submitting this Report to the Minister, minuted --

> "The report by Dr. Bradfield and the accompanying statement of record by Miss Butler regarding the work of the Staff in England and the arrangements arrived at with the Contractors on different points in relation to the design and the Contract, are submitted for the information of the Minister.
>
> "A perusal of the documents will I think satisfy the Minister that the work of the Staff prior to

Dr. Bradfield's arrival, and what was done subsequently, was of great importance, was faithfully carried out and fully justifies the selection made; further, that the various matters requiring attention have been dealt with in a manner that should simplify and facilitate the working out of many of the intricate detail operations of the Contractors.

"Summarised in briefest terms, taking the matters seriatim as in Dr. Bradfield's report, while increasing the thickness of the concrete decking from 3" to 4", re-designing and increasing the weight of the main bearings, yet by the elimination of over-run in the weight of plates, lowering of arch trusses and the substitution of concrete for granite skewbacks under the bearings, a net saving of £94,000 has been achieved, assuming the Tariff Board remits duty to the extent of £34,000 as the decisions would appear to indicate would be the case.

"It is satisfactory to note also from the report and statement that the Contractors have apparently met the Department's representative in the matters dealt with in a spirit that augurs well for the future satisfactory carrying on of the work.

"One matter the Minister has already had directly under his notice in an elevation plan which Dr. Bradfield placed before him, and which shewed the amended method of treatment consequent on the lowering of the arch 10' 6".

"Referring to this in the report, Dr. Bradfield points out that by giving the towers a battered face below the deck the position has been met without militating against the appearance of the Bridge.

"Expressing the opinion of a layman, I am not at all sure that public opinion will be unanimous in that view, as I personally feel that the considerable spaces now intended between the main steel structure itself and the towers will give the Bridge a detached look, as from these features, that will not be as pleasing as the treatment previously proposed."

Before/

Before leaving London in November, 1924, I approved of and signed 24 detail drawings of typical members of the arch and other details of the Bridge, thus determining the type of detail which had to be incorporated in the working drawings when submitted for my check and approval by the Contractors. I wrote stating --

> "I have to point out that these plans have been signed as type plans only, and that make-up of members, details, etc., are subject to variation when the final calculations are checked."

Before leaving London, I outlined in conversation the Plans I would require, just those necessary for the fabrication and erection of the Bridge. These Plans of the details are, under the Contract, made in London by the Consulting Engineers to the Contractors, and submitted by the Contractors to me for approval. I have no direct dealings with the Consulting Engineers to the Contractors. If the details do not meet with my approval, they are amended, the amendments I require being outlined in my letters to the Contractors.

Every Plan, including the dimensions of every stone in each course of masonry, has been reviewed and approved by me before work could be proceeded with.

All important features of the Bridge, as erected, are as laid down in my Plans and Specification when submitted for tenders. The arch is 60 feet deep at the centre and 98' 6" wide

between/

between centres of trusses. The deck accommodation is identical, with stringer spacings exactly as I had arranged them, the deck is carried by built-up hangers connected to the cross-girders by pins at the lower ends and riveted to gusset plates under the bottom chord at the upper ends. In the Plans calling for tenders, the hangers were pin-connected at both ends. The deck is braced by the system of laterals as required by the Type Plans incorporated with the Specification when calling for tenders.

In the main trusses, all chord members are made up of four web plates with top and bottom angles and flange plates, diaphragms with manholes are provided as shown in the Plans accompanying the Specification. The trusses are braced by top and bottom lateral systems, riveted to the lateral gusset plates. In Dorman, Long & Co's. tender, these lateral systems were pin-connected, but this was found to be unworkable and the system as set out by me in the Official Plans had to be reverted to.

Matters of detail were subject to final determination as the calculations proceeded. The make-up of the main arch members, for instance, was only finally determined after an extensive series of calculations and revisions had been made as the weights and sections approached finality.

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The sectional areas of the main truss members as decided by me were based on the calculations performed by my Officers and myself, not on the bare summary of calculations forwarded by the Contractors, and with which calculations I did not always agree.

To minimise field riveting, the top and bottom chords of the arch were planned in two widths longitudinally instead of four as provided for in tender.

The erection scheme was modified with my consent to allow all the anchorage cables to be attached at the tops of the end posts of the arch, instead of being connected at the fifth panel point and passing over a built-up steel strut on top of the end posts as submitted with tender. This change affected the basis of the calculations and was responsible for considerable variation in the sections of members; it also minimised the risks attendant on the erection of the arch.

These facts disclose that even after the extensive work of preparation of the details by the Consulting Engineers to the Contractors with all unavoidable revisions and adjustments in detail inseparable from this "pons mirabilis" of the Engineering world, the vital features are maintained in the structure as it stands today practically identical with those shown in my Plans and as required by my Specification when tenders were invited.

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The main bridge as constructed is a two-hinged arch of 1,650 feet span with five approach spans on either side, the total length of steel structure being 3,770 feet, as provided for in the Specification and Plans upon which tenders were invited.

The main span comprises two silicon steel arches 98' 6" apart, centre to centre, set in vertical planes having a span of 1,650 feet and a rise of 350 feet. The depth of the truss at the crown is 60 feet and at the end posts 187' 9"; whilst the highest point of the steelwork at the centre of the top chord is 437' 6" above Standard Datum, the topmost point of the arch is 440 feet above mean sea level.

Each arch truss is divided into 28 panels with a single system of bracing and the two trusses are braced together by systems of laterals in the planes of the top and bottom chords. The lower chord varies in depth from 48 inches at the crown to 99 inches at the hinges, the width 11 feet overall being uniform throughout, the cross-sectional area at the crown is 1,060 sq. inches and at the main bearings 2,700 sq. inches or over 18 sq. feet of solid steel. The top chord is 40 inches deep and 11 feet wide throughout, except in each end panel where the chord was tapered to provide sufficient depth at the end posts for the 27-inch erection pin connection.

All main members are of silicon steel; the heaviest angle

used/

used is 12 x 12 x 1¼ inches; the thickest plate 2 1/8 inches and the largest rivet 1 13/32 inches in diameter with a grip of 12 inches, larger than any rivets hitherto required in any bridge. There are 50,300 tons of steelwork in the completed Bridge, of which 37,000 tons is in the main arch span, there are about 600,000 individual parts and 5,500,000 rivets in the structure.

In my report to the Minister for Public Works, dated February 24th, 1915, I stated --

> "To secure the cheapest and most efficient Bridge, the following course is recommended:- 'Alternative tenders to be called for local manufacture and for importation on plans and specifications, fixing the essential features only, and leaving the details of construction and the choice of steel to Tenderers. The successful Tenderer to complete the working plans to the satisfaction of the Public Works Department."

That recommendation, made 16 years ago, has been carried out in its entirety.

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THE SYDNEY HARBOUR BRIDGE.

Work Preparatory to Construction.

To enable the Bridge to be fabricated and erected, it was necessary to make available the land on the northern foreshores of the Harbour between Jeffrey Street and the Railway and Ferry Station as now erected midway between Milson's Point and Lavender Bay. This involved --

(a) The diversion of the railway passenger traffic from Milson's Point to the new station at Lavender Bay.

(b) The diversion of the tramway passenger traffic from Milson's Point along Dind Street and Glen Street to the new station.

(c) The diversion of the motor 'bus passenger traffic from Milson's Point to the new station.

(d) The diversion of the Milson's Point passenger ferry to the ferry station at Lavender Bay.

(e) The diversion of the vehicular ferry traffic from Milson's Point to new ferry docks at Jeffrey Street.

To make proper provision for the railway passenger traffic it was necessary to remodel and repair the railway station which had been erected some years previously. The overhead bridge and stairways from the platforms to the ferry were demolished and access given to the ferry by means of a concourse connecting the ends of the platforms, obviating the climbing of stairways by the railway passengers, as had been necessary when the station was previously in operation.

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To give the tramway passengers direct access with the new ferry, the tramway has been diverted along Dind Street to Glen Street, which street is parallel to the new railway station and ferry wharf, but is some 40 feet higher.

To enable motor 'bus and other vehicular traffic to serve the new station, it was necessary to widen Dind Street and Glen Street, also to provide a 'bus and cab stand adjacent to the station where passengers could load and unload without interfering with the traffic in Glen Street.

To give the tramway and motor 'bus passengers and other pedestrians ready access from Glen Street to the railway station and ferry, three escalators or moving staircases having a rise of 35 feet have been provided; these escalators have a passenger capacity each of 10,000 per hour. For passengers who will not use the escalators, two stairways 7 feet wide have been provided, also an electric lift for elderly or maimed people.

To make provision for the ready access of the railway, tramway and other passengers to and from the ferry steamers, barriers to separate the incoming from the outgoing traffic were erected on the wharf, the ramps were altered and a large reinforced concrete pontoon provided.

In the five hours Sunday night July 27th, 1924, at 11.30 p.m. and Monday morning, July 28th, at 4.30 a.m., the necessary alterations were made to the railway and tramway tracks and to

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the railway station to enable the changeover to be made at 4.30 a.m. on July 28th, 1924, as arranged.

The transfer of the station from Milson's Point was carefully thought out and was carried out without inconvenience to the travelling public; the facilities provided for dealing with the railway, tramway and other pedestrian traffic have worked well and have given complete satisfaction.

The last train arrived at the old Milson's Point Station at 11 p.m. on the Sunday night, July 28th, and in the five hours 11 p.m. to 4 a.m., the changeover had to be made. The all night service via the tram to Milson's Point ferry was maintained, the passengers having to walk a short distance to the ferry whilst the connection was being made in Alfred Street to divert the tramway from Milson's Point to its present position at the top of the escalators in Glen Street.

The escalator nearest to the station was completed and was kept running for nearly six weeks before the station was opened. The first passenger on the escalator was being carried down to the railway station at half past four in the morning. When nearing the bottom, the escalator stuck and though every endeavour was made to rectify it, the escalator could not be brought into operation until 9 o'clock that evening, since when it has run without a hitch. The other two escalators worked perfectly, one up the other down. The Press wanted to know why

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the third escalator was not in use, so I asked the reporters if they thought such extravagance necessary, as the other two were dealing with the traffic quite satisfactorily. You cannot guarantee everything working to schedule in a traffic change-over.

To enable the vehicular ferry traffic to be diverted to Jeffrey Street, new ferry docks in duplicate, capable of accommodating the largest vehicular ferry punts have been constructed. The flaps of the docks can be operated electrically and by hand. A new roadway has been constructed from the Jeffrey Street Ferry docks parallel to Alfred Street as far as Broughton Street. By routing the traffic along Pitt, Fitzroy, Burton, Broughton and McDougal Streets, the vehicular traffic has been kept clear of the Approaches and clear of all danger during all stages of construction. The vehicular ferry docks and the roads in approach as far as Pitt Street were completed on June 30th, 1925.

The North Shore Ferry Company began its operations in 1861, and before it was disfigured by the ferry docks and timber yards, Milson's Point was a scene of cylvan beauty. One notable tree, a Port Jackson Fig, was beautiful when Governor Phillip founded Sydney, on the opposite side of the Harbour. This tree withstood the shock of storm and chance for over a century, it was walled around to preserve it when the road was made along Alfred Street to Milson's Point, but on December 31st, 1900, the day

before/

before the Commonwealth was inaugurated, the old landmark was blown down during a severe storm.

The area under the Bridge at Milson's Point will be transformed into a park, a beauty spot again, planted with native trees and flowering shrubs.

Whilst the transfer of the traffic services was being made, the resumption of the land required for construction purposes was undertaken.

On the City side, most of the properties resumed were on the Rocks Area and were owned by the State, they were acquired thirty years ago when the epidemic of bubonic plague broke out. The buildings were mostly old, many dilapidated and of little value. Three hundred and thirty-three buildings have been demolished, the most notable being old Scots' Church, erected in 1826 by Dr. Lang, that stormy petrel of the Kirk. The Colonial Treasury had contributed 2,400 Spanish dollars to the building fund and though the Colonial Office directed Governor Darling to insist on repayment, and though Darling and Lang were not bosom friends, there is no record of any refund. Would that be called repudiation today? Fancy that hard-headed old Presbyterian setting the example.

Owing to the improvement of the area by the construction of the Highway, the value of the residues should be about double the cost of their acquisition, about £472,000, i.e., the resale value should be about one million pounds.

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On the Northern side generally, a thickly built on old residential area was acquired at a cost of £780,000 and 469 properties were demolished. The resale value and the rental value of the shopping facilities provided should return interest on an additional half million, so eventually the land resumption costs will be balanced by the resale of residues.

In all, 802 buildings have disappeared; this sounds quite matter of fact, but there were many touches of pathos when owners of properties, grown grey in occupation, heard they must find residences elsewhere. These interviews were the most trying phase of the construction of the Bridge, most of those interviewed were genuine, others were sparring for time and cash. I was blamed for everything, even for migrating the rats of North Sydney to Mosman, perhaps they went as a delegation from the North Sydney Council to let the Mayor and Aldermen of Mosman know that the ceremony of Turning the First Sod had taken place.

Wherever possible, revenue-producing facilities have been constructed in the Approaches, so that the rents derived therefrom may offset the cost of construction. There are ten openings fronting Junction Street, North Sydney, with a shopping frontage of 400 feet, whilst between Burton and Alfred Streets, fronting Broughton Street as now extended, will be a further twenty-two openings, having a shopping frontage of 800 feet. On the other side of the road is an area of about 2½ acres, an

excellent/

excellent site for an up-to-date hotel and modern parking station, as it is in close proximity to Milson's Point Station. These facilities and the shops at the entrances to Milson's Point and North Sydney Stations, should, at no very distant date, return sufficient revenue to pay interest on a capital sum of a quarter of a million pounds sterling. The balance of the cost of resumption, about £1,100,000 in normal times, should be derived from the sale of the residues on both sides of the Harbour.

Before construction could be entered upon, the position of the Bridge had to be definitely located and its centre line established.

Strolling through the Gardens, a visitor might by chance notice several cast iron boxes set unobstrusively in the turf, but to connect these boxes with the location of the Bridge would hardly occur to anyone. There are eight boxes in all, three in the Gardens and one on Government House lawn, which mark the ends of the two base lines used in triangulating the centre line of the Bridge. A box is located at Milson's Point and another at Dawes' Point, these two were located on the centre line of the Bridge, as fixed after preliminary surveys, the other two are located one at Kirribilli, the other at Mrs. Macquarie's Chair. In each box, embedded in concrete, is a plug with a centre pop, the problem to be solved was to

determine/

determine with the greatest exactitude possible the distance between the centres of the two plugs located on the centre line of the Bridge.

The survey was made by Mr. E. A. Amphlett, B.E., Licensed Surveyor, Mr. Amphlett and myself were fellow students in Engineering and graduated the same year. For the purpose of this survey, when in England I purchased modern instruments specially made by Messrs. E. R. Watts & Sons, London. The theodolite is an 8-inch instrument of the repeating circle pattern the angles were each read 24 times and the mean obtained. The error in closing the three angles of a triangle averages 1/4 of a second, equivalent to 1/16 of an inch in a sight 1 mile long.

The 23-inch level is of great sensibility and high magnifying power and can be read accurately to less than 1/8 of an inch in 1,650 feet, the distance between the centres of bearings of the main span.

The invar steel tapes are composed of 63% steel, 36% nickel with traces of manganese silicon and chromium, the level and the theodolite were all tested at the National Physical Laboratory at Teddington, prior to leaving England.

The coefficient of linear expansion of the tape was -0.0000003-inch for each degree centigrade under a tension of 20 lbs., the minus sign indicating that the tape decreased in

length/

length as the temperature increased, so the tape was for all practical purposes uninfluenced by heat or cold. By means of straining trestles and tripods, the length of each base line was measured with the greatest accuracy humanly possible and from the stations at the ends of each base line the angles between the lines connecting these stations with the two stations on the centre line, and with the stations at Kirribilli and Mrs. Macquarie's Chair were accurately read. Knowing the length of the base lines as measured and the three angles of the various triangles, the length of the third side between the centres of the two plugs in the boxes on the centre line of the Bridge could be calculated, Mathematica, the Queen of the Sciences, lending her aid to the Engineer.

The 8-inch Watts' theodolite weighed 120 lbs. and to avoid errors due to settlement in the earth, three concrete blocks were sunk in the ground at each station, a steel pin being embedded in each block to support the weight of the instrument. The length between the centres of the plugs established on the centre line of the Bridge was determined to be 2268.45 feet. The survey was checked by Mr. R. J. Butler, B.E., and the subsequent setting out of the structure was done by him. The most suitable position for the bearing on the southern side was then fixed and its distance from the station at Dawes' Point measured along the centre line as established. By adding this

measurement/

measurement to 1,650 feet, i.e., the distance between the centres of the bearings of the arch span and subtracting the sum of these two from the total distance of 2268.45 gave the distance which the northern bearing had to be fixed from the northern station on the centre line.

The two arch trusses are 1,650 feet span centre to centre of bearings spaced 98' 6" apart horizontally centre to centre so the four pin bearings had to be established to form a perfect rectangle of length 1,650 feet and width 98' 6", the centres of all four bearing pins to be at the level 27.5 feet above mean sea level. Concrete instrument towers were built on the centre line of the Bridge exactly 1,650 feet apart and of such a height that the line of sight of the level when set on the instrument tower would be approximately at the same height as the centre line of the bearing pins.

It will thus be seen that every precaution was taken to determine accurately the centre line of the Bridge and the positions of the four main bearing pins. When the heavy bearings weighing 296 tons each were in position on the supporting jacks and steel frames, the position of each pin was again carefully checked. The concrete seating had to be poured below each bearing after it was erected and observations made on all four of the bearings after the concrete base had set did not disclose any error in the rectangularity or

horizontality/

horizontality of the four bearings.

This broadcast will have given some idea of the preliminary work which had to be accomplished before construction could be commenced and the method of the location of the four main bearings. It all sounds simple and it was most interesting, especially when Mr. Amphlett, in his zeal for the accuracy of his survey, drove two survey pegs, six years ago, in the tennis lawn attached to Government House. The band didn't play "God Save Amphlett" or even the King, that day. However, the Bridge is accurately located, its bearings four square with each other and in line and level, and the Arch now Colossus-like bestrides the Harbour.

I might add that the traffic changeover was the largest in the history of Sydney, involving train, tram, 'bus, passenger and vehicular ferries, and the whole has worked perfectly. On March 20th next, these services will be running across the Bridge.

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THE SYDNEY HARBOUR BRIDGE.

Construction of Substructure -- Main Bridge.

On January 19th, 1925, the Contractors began the construction of the substructure of the Main Bridge.

During the first month, efforts were concentrated in erecting the plant, the air compressors, the cranes and rail haulage tracks also in arranging electricity supplies, etc. The old stone retaining wall which bounded the southern side of Hickson Road at Dawes' Point was demolished, also the Water Police Station and other old buildings on the area and the old battery. This old battery was circular in shape, the old forty-five pounder cannon were in position on their teak gun carriages, which were in an excellent state of preservation. The cannon and gun carriages were removed and stored. When rehabilitating the Park a few months ago, the relocation of these cannon was a problem, the Military Authorities had no use for them, neither had I, they weighed about 5 tons each and could not well be re-established under the Bridge. I got in touch with Colonel Spain, and offered them to him, for the Zoo, and there they are at Taronga Park, all painted and furbished, the delight of the children, and I believe, the Colonel.

When demolishing the old Water Police Station, bricks

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with the broad arrow impressed in them, also a stone was discovered, this stone was inscribed with the letters R. R. 1789, the initials of Robert Ross, Lieutenant-Governor, who came out in the first fleet in 1788. It was evidently one of the first stones quarried in Australia and probably was used in the astronomical station erected by Lieutenant Dawes on this area soon after the landing in Sydney Cove. I gave the stone to the Historical Society.

On the northern side, a tombstone was unearthed bearing the inscription --

"Sacred to the Memory of Peter Crawfurd, First Officer of the Ship "Surrey" who died of Typhus Fever in 1806."

This stone is also in the archives of the Historical Society.

The construction of piers and abutments for the approach spans at Dawes' Point and the retaining wall along Hickson Road was first proceeded with.

The rock was excavated by drilling jack-hammer holes and using gelignite explosive, the excavated material was then handled in steel boxes by the locomotive cranes, tipped into barges and towed out to sea and dumped there.

On June 4th, 1925, the work was sufficiently advanced for the first batch of concrete to be placed in the retaining wall, this was the first batch of concrete used in the construction of the Main Bridge, and the mixer was started on that occasion

by/

by Mrs. Ennis.

Work on the retaining wall along Hickson Road proceeded rapidly. It was a gravity section wall, the foundations were found usually just below street level with one exception, where at the foot of Pier No. 4 a small localised "greasyback" which had a steep slope towards the front of the wall, necessitated the foundation level being taken down several feet below sea level.

Each terminal abutment consisted of two concrete blocks 19 ft. x 16 ft. battered 1 in 30 on the face. The walling between these concrete blocks was later built at the end of each terminal approach span. When the two abutment blocks were built, steam locomotive cranes were erected on them and built the trestling from the abutments towards the first set of piers, working forward on the trestling as it was erected and on this trestling the steel girder approach spans were afterwards constructed. When the cranes could command the first pair of piers, their construction was put in hand and built by the cranes, the method being to set a full course of granite around the sides of the pier, then to concrete the area enclosed by the course and thus proceed, course by course, to the top. The concrete in the main body of the piers was composed of 5 parts granite aggregate, 2¼ parts sand and 1 part of cement, 1:2¼:5, using for aggregate the run of

crusher/

crusher from 2½ inch down, excluding the dust. For the top 3 feet of each pier directly under the bearings of the steel girders the concrete was made richer, 3 parts of granite aggregate to 1½ parts of sand to 1 of cement being used.

As each pair of piers was completed, the locomotive cranes ran over the tops of them on rails and erected the timber trestles, up to the next pair of piers, which were then built. Each pier is 14 ft. x 17 ft. at the top, the sides are battered 1 in 30, they vary in height, the highest pier, No. 18, adjacent to the eastern side of the pylon at Milson's Point, is 79 feet high.

The construction of the piers for the approach spans and the retaining wall along Hickson Road proceeded rapidly, the first granite stone placed in the work was the south-western corner stone of Pier No. 2, adjacent to the Mining Museum. This stone was laid by Mrs. Bradfield on October 7th, 1925.

After the piers were constructed, and the lower sections of the cast steel bearings were set in position on steel wedges, the holding down bolts being left free in core holes in the piers, the top sections of the bearings were then placed in position and the steel members of the trusses then erected. The bearings were not concreted in position straight away in case there should be any inaccuracies in the fabrica-

tion/

tion of the members of the trusses which might have had to be adjusted. In no case, however, was it found necessary to make any adjustment in the bearings.

All piers at Dawes' Point were completed in February, 1927, and at Milson's Point in October, 1927. The rate of progress depended very largely on the output of granite masonry and concrete aggregate from the Quarry at Moruya.

The granite for facing the piers, abutment towers and pylons came from Moruya where the Government owned a quarry from which the stone rip rap for protecting the banks of the Moruya River was obtained many years ago. The Contractors subsequently purchased an area of land adjacent to the Government Quarry, but in the Government area there is enough stone in sight to build several bridges of the size of Sydney's Bridge.

The outcrop of granite is on the bank of the river about 1½ miles from the town and about the same distance from the river entrance, and 170 miles by sea from Sydney. The appearance of the granite was in its favour, the black biotite mica, giving the stone a pleasing appearance, sparkling in the sun and so enhancing the beauty of the white quartz and felspar. The quality was all that could be desired; tests showed it to have a crushing strength of about 1,200 tons per square foot.

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To house their masons, the Company had to build a settlement, Granite Town, some 60 houses each consisting of four rooms with wash and outhouses and provided with water and sanitation at rentals of 9/- and 11/- per week.

The Quarry Master for the Contractors, Mr. Gilmore, came from Aberdeen, he told me that at Aberdeen he would have had to wait months to get stones from the Quarries there of the dimensions required for the Bridge. Here he just quarried in at the face and cut blocks of almost any size from which blocks, after allowing for waste, numbers of the largest stones could readily be obtained. In all, about 40,000 stones were cut and dressed at Moruya, and stored there to be delivered at the Bridge site as required.

Among the Gilmore children was a little girl of three, who told me she came from Scotland to "Mak' a Brig', "in Australian, to "Make a Bridge."

Apart from the quality of the stone, the quarry proved to be an excellent one for working. Blocks of granite, the largest about 2,000 tons in weight, were quarried. These blocks were cut to suitable sizes from which the finished stones could be dressed. The blocks were split by plug and feather. The men in charge of this operation were skilled and expert in recognising the grain in the granite and where to locate the line of plugs and feathers, which, by light

hammer/

hammer blows, gradually split the stone in two.

The blocks in their rough shape were hauled by petrol locos. to the dressing sheds.

In the dressing sheds, margin drafts were cut on the blocks preparatory to the required surface finish being completed. Two classes of exposed surface finish were used, rock face and four-cut, the former being that of the stone as it left the quarry or as split by plug and feather, the latter was obtained by dressing the face down to a plane surface by hand or with pneumatic hammers having for a cutting face a group of four chisel edges per square inch.

Most of the four-cut work was done in the open air -- the machines had to be spaced 20 feet apart to allow for the regulation air space between each machine worker on account of the dust.

The culls and pieces not large enough to make dressed stones were spalled by means of a 2½ ton steel ball and by hand until the granite was broken small enough to be loaded by hand into skips and tipped into the jaws of the crusher.

After crushing, the aggregate the run of the crusher was carried up to a slowly revolving and slightly inclined tubular screen where the crushed granite was automatically graded, the various sizes of aggregate dropping through the dif-

ferent/

ferent sized openings in the screen to the bins below. A conveyor ran beneath the bins and carried the crushed stone up to a chute by means of which it was located directly in the freighters.

The storage bin had a capacity of 800 tons.

Three freighters, each having a carrying capacity of 400 tons on 8 feet draught, were built to carry the aggregate and dressed stone from Moruya to Sydney. Three freighters also carried water to the settlement from Sydney as ballast on their return trips. They were subsequently sold and the granite brought up by the boats of the Illawarra Steam Navigation Company.

The piers and abutments of the approach spans and the granite have been briefly described and now for my awful abutment towers and pylons which were necessary for the erection of the Bridge as well as for its architectural adornment. Without them, the up grade of the deck of the approach girders, the steep curve of the arch, the sheer vertical end posts of the arch, and the steel pier carried up from the skewback to support the end of the approach span and parallel to the end post of the arch would have made an inharmonious combination of our lines most unsightly, whilst the huge arch itself springing from relative small skewbacks at ground level would have had an abruptness of take off altogether displeasing.

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As will be explained in a subsequent broadcast, the abutment towers were necessary for the erection of the Bridge, they certainly add to its appearance.

To satisfy the aesthetic principal that "Truth is Beauty", it was necessary to provide some massive construction at the abutments of the main span to establish a visible as well as an actual resistance to the enormous thrust of the arch. At the same time it had to be clearly shown that the arch is supported solely by the main bearings near the bases of the abutment towers, the top chords of the arch being entirely dissociated from the masonry structure.

The abutment towers stand well back from the end post of the arch with a front face battered below deck level, springing from the skewbacks. The weight of the front part of the abutment tower is carried by the skewbacks and tends to steepen the resultant thrust from the arch, and so reduced the size of the skewbacks.

Incorporated in the foundations of the abutment tower are the four independent skewbacks, one for each corner of the arch span. The main bearing is seated at an angle of 45° so that the level of the centre of the main pin is 27' 6" above standard datum, and the load from the arch is transferred through the bearing to its base, 24 ft. wide by 21 ft. deep.

The skewbacks beneath the bearing are built of concrete

each/

each 90 ft. long, 40 ft. wide, carried down to a solid sandstone foundation. The deepest foundation is on the southern side, it was carried down to 35 ft. below standard datum because a band of shale about 3 ft. thick was met with just where it was intended to found the skewback, and is practically level across the base. The northern skewback foundations are stepped upwards and backwards more at right angles to the resultant thrust.

Deposition of such a mass of concrete, approximately 7,600 cubic yards, to carry an inclined load of over 20,000 tons, was a matter that needed careful investigation. Dr. Otto Faber, on behalf of the Contractors recommended the placing of the concrete in individual blocks of the full 40 feet width of the skewback, each block of rectangular cross-section 8 ft. long and 4 ft. deep, with the blocks breaking bond, so that the thrust would be carried down to the foundation without fear of weakness at the construction joint. When the foundation levels had been determined, this scheme was revised, the blocks were made of a flattened hexagon cross-section, 8 ft. wide and 4 ft. 6 in. deep, and poured the full width of the skewback. By this means, the shrinkage effect of the setting of the concrete was reduced to a minimum and the monolithic structure of the skewback was maintained.

Immediately under the bearing, a layer of special concrete

was/

was poured, to take the pressure averaging 800 lbs. per sq. in. This concrete was proportioned as a result of special investigations by me. Using 2 parts of specially graded granite aggregate, to 3/4 part of Nepean sand, and 1 part of special Kandos cement, the concrete had a compressive strength of 6,800 lbs. per sq. in. at 28 days, and 8,050 lbs. per sq. in. after 3 months' hardening. The layer of concrete beneath the bearings averaged 5 ft. in thickness and was reinforced by a network of reinforcing bars 1¼ ins. diameter. Each slab of concrete 160 cubic yards, was poured continuously, each batch being mixed for 3 minutes with the minimum of water.

A lower layer of special concrete was used to embed the 4½ in. diameter holding down bolts for the main bearings. This concrete was developed also as a result of special tests, and consisted of 3 parts of graded granite aggregate to 1½ parts of Nepean sand, and 1 part of Kandos cement, giving a compressive strength of 4,300 lbs. per sq. in. at 28 days.

Each abutment tower above the skewbacks is 225 ft. wide across the Bridge, and 162 ft. long in the direction of the Bridge at foundation level. The towers are 285 ft. above mean sea level to the top of the granite parapet, and 291.50 ft. to the top of the concrete roof. The base of the tower up to Level 55.00 is faced with heavy four-cut and rock-faced granite in courses of 4 ft. depth, forming a front apron with

shingled/

shingled surface, and a heavy plinth relieved on the sides by a rectangular panel of four-cut work surmounting a lateral projection with a moulded capping course. The land side wall is pierced at ground level by a doorway 20 ft. wide x 20 ft. high.

Above the plinth, inside elevation the towers are battered at 1 in 40 on the land side, 1 in 30 on the Harbour side. The shingled face is battered 1 to 1. At Level 120.00 the side walls are pierced by two slit openings 2' 6" wide, 16 ft. high. On the back face, a projecting wall is carried up to Level 117.50 to take the approach span bearings, which are 150 ft. distant from the main arch pins.

At deck level, the side walls are pierced by arch openings 20 ft. wide, 34 ft. high, the outer opening surmounting a projecting balcony with parapet and supporting corbels. From these four balconies, superb views of the Metropolitan Area are obtained. Similar arched openings in the front and back walls accommodate the outer railway track and footway of the Bridge. At Level 214.00, the batters change and the tower top is formed by a succession of chamfers and batters until the masonry ends at Level 285 above mean sea level. The masonry in general is rock-faced relieved by margin drafts, corner checks, corbels and special details of four-

cut/

cut work.

Looking along the line of the Bridge at the front wall the side walls are battered at 1 in 40, the front wall with its central feature extends unbroken from the plinth to level 136.50. Above deck level the towers take the form of two separate pylons, each pierced by an arched opening for the railway and footway. The batters of the side walls of each pylon are 1 in 40, changing at Level 214 as on the side elevation, a succession of chamfers and batters.

The arched openings at deck level are faced in four-cut granite up to the springing level of the arches, the intrados of these openings being of plain concrete.

Internally, the abutment towers below deck level consist of two massive piers above the skewbacks, and two piers supporting the approach span on the landward side. The four piers are connected by front, back, side and internal curtain walls, forming three hollow cells. The central cell is 95 ft. wide by about 118 ft. at the bottom, decreasing with the batter of the front and rear walls. Each outer cell is 41 ft. wide by 78 ft. long at the base, the internal walls are 4 ft. thick, pierced at ground level by openings to give access from the central to each outer cell.

At Level 155.50, the back and front curtain walls cease,

and/

and the two outer cells are roofed over by a reinforced concrete slab 2 ft. thick supported on reinforced concrete main "T" beams 9 ft. deep overall, 3' 6" wide reinforced with 21 bars 2 ins. diameter on the lower flange, and subsidiary "T" beams 4' 11" deep and 2' 3" wide reinforced with 7 bars 1½ ins. wide. The main beams are 38' 4" clear span, subsidiary beams 24' 6 5/8" span centres. This floor formed a platform for the erection of the creeper crane and separates the lower portion of the abutment tower from the pylon above. The steelwork forming the traffic bridge through the towers is carried by steel cross girders, one of which rests on bearings on the internal walls of the pylon, and the other rests on top of the skewback piers. The footways here are an integral part of the tower, being constructed of reinforced concrete supported on columns rising from the floor at 155.50. The two pylons are inter-connected at this level by a steel transverse footway 7 ft. wide, which is connected at its centre to a steel stairway 6' 6" wide, enclosing a liftwell, the stairway rising from the floor of the pylon at ground level, a lift can be installed when required. From Level 155.50, access is gained to the Main Bridge footway at Level 171.25 by steel stairs 3 ft. wide inside each of the outer legs of the pylon walls, the stairway ascending 6 ft. wide to a cross slab above the arch openings at Level 209.17

Up/

Up to the slab Level 155.50 and above the base level at 27.50, the abutment towers were erected as a concrete shell with outer walls generally 3' 6" thick, reinforced by horizontal bars 7/8 in. diameter, at the rate of one per course. The masonry facing was added more slowly, building up the thickness of outer walls to 5' 6". The walls were made of uniform thickness, i.e., the inside face of the wall follows the batter of the outer granite face. The masonry blocks were cramped back to the concrete shell walls by steel cramps let into the dowel holes in the stones, and into holes drilled in the concrete shell.

Above deck level the pylons were constructed course by course and the concrete poured behind each course as erected. At the slab above the arched openings two transverse internal walls each 2' 6" thick divide the pylon into three compartments, the two outer cells being 24 ft. by 33' 6" and the central cell 19 ft. by 33' 6". In one outer cell a steel stairway ascends to the next slab level at 251.75, where external lookouts are provided on the side walls of the pylons. The internal cross-walls terminate at this level the floor being 63 ft. by 29 ft.

A further steel stairway ascends to the top slab at Level 280.50 where the floor is 49 ft. by 15 ft., the whole being covered with a Mansard roof 11 ft. high, the top of the

roof/

roof level is 291.50. Doorways at Level 280.50 lead to an outside walk 4 ft. wide round the top of the tower 171' 6" round, which is protected by a granite parapet terminating at Level 285.00.

There are 115,000 cubic yards of concrete, 16,500 cubic yards of granite and 715 tons of reinforcing steel in the two abutment towers.

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THE SYDNEY HARBOUR BRIDGE.

Main Bridge -- Fabrication of Steelwork.

The Specification provided that all materials manufactured in New South Wales at the date of the closing of tenders should be utilised, also that the metalwork should be fabricated, either wholly, or as far as reasonably practicable, in New South Wales.

Of the 52,570 tons of steel delivered for the Bridge, 42,290 tons came from England and 10,280 tons from Australia, but the fabrication of the whole of the steelwork was carried out in the workshops at Milson's Point.

The works comprised a light fabricating shop 580 ft. x 130 ft. divided into two bays and with a large template floor 200 ft. x 130 ft. built over one end, and a heavy fabricating shop 500 ft. x 147 ft. in which the assembly of the members for the main span trusses was carried out.

Power for operating the many independently motored machines and cranes was obtained from the Railway Commissioners' mains at 6,600 volts and transformed to a voltage of 440 in the substation at the site.

The hydraulic pumps and air compressors for operating the riveting hammers, also the fitting shop, and blacksmith's shop for tool maintenance, were placed adjoining the light shop.

Stores/

Stores, First Aid Room and Paint Shop were situated near the heavy shop.

All the steel plates and sections and also the rivets required in the fabrication of the Bridge were delivered to the wharf alongside the light fabricating shop.

Two 10-ton travelling wharf cranes unloaded this material direct from the ships' holds or from lighters to the benches of the adjacent stockyard where it was picked up and stacked, or taken to the transverse bay at the end of the light shop by two 5-ton semi-goliath travelling cranes.

The plates were straightened in the large plate rolling machine at the end of the stockyard.

This machine handled some of the largest plates used, the arrangement of the rollers enabling the plate to be "curled" in a decided sweep before straightening, which proved to be the best way of removing small buckles.

The section straightening machine adjacent to the transverse bay of the light shop was used to remove buckles from angles and angle straps and to camber roadway and footway joists.

The shearing and planing of plates, and cropping and sawing of sections were carried out in the transverse bay of the light shop, all material being handled by a double crab

10-ton/

10-ton overhead crane.

Material was brought in from the stockyard as required by the fabrication programme, straightened if necessary, and then the length marked off for cropping and shearing.

Plates up to 1¾ ins. thick were sheared in the heavy plate shear, but some of the large, heavy silicon steel plates were planed to the correct length, as these plates were so large that they were up to the limit of what could be manufactured.

Angles up to 8 x 8 x 1 were cropped to length in the double jaw angle cropper, the 12 x 12 angles, and other heavy sections were sawn to length by a 38 ins. diameter cold saw.

There were two plate edge planing machines in the transverse bay, one with a 28 ft. bed plate and the other with a 66 ft. bed plate, this is the largest planing machine of its type extant.

The whole of the marking off and drilling, with the exception of the opening out of splices and gusset connections and also the riveting of webs was carried out in the light fabricating shop which was divided into two bays each served by two 25-ton overhead travelling cranes each with a 10-ton auxiliary.

In order that all steel tapes used for marking should be standard, a measuring base 100 ft. long consisting of a 2 x 3/8 flat steel bar was laid out on the template floor, and

standardised/

standardised to read 100 ft. at a temperature 72°. All tapes were checked with this standard. The tape having the same coefficient of expansion as the steel flat bar ensured that the lengths would be standard at the standard temperature of the tape 72°, whatever the temperature was at the time the marking was done.

The web and flange plates of members and also the gusset plates of the truss intersections were drilled from a master template which was one of the group of sixteen similar plates required.

The rivet holes and correct length and matching lines were marked on this plate direct from the drawing, by skilled men.

The marking off also showed the size to which holes were to be drilled and also those which were to be used as tack bolting holes in the assembly for drilling.

The plates were then passed on to the drilling machines and drilled in bundles of three or more depending on the thickness of the material to be drilled.

Angles were marked off with a centre punch through timber templates which had been set out by the markers-off on the template floor. The holes in the end splice portion were ringed and popped to ensure accurate drilling.

In/

In order that the full sized holes in which the rivets were to be driven would be in true alignment through the several thicknesses of material of the web flanges, solid drilling was employed.

In this method the holes in the angles and plates were first drilled to a size generally 1/8 in. smaller than the finished diameter. The drills were air hardened steel, the lubricant, soapy water with a little oil. The holes were drilled at speeds up to 3½ ins. per minute.

The diameter of the hole for all sizes of rivets was 1/32 in. larger than the rivet when cold. The smallest rivet was 21/32 inch in diameter and the largest rivet $1^{13}/32$ ins.

Before riveting, the drilling fin was removed from all holes by countersinking the holes about 1/16 in.

The rivets in the bottom chord webs were driven by an 80-ton hydraulic riveting machine hung from a travelling gantry, three 45-ton machines were used for riveting webs of other truss members, laterals, cross-girders and stringers.

All rivets were heated in oil furnaces, the oil being sprayed in by means of a combination jet operated by compressed air. In the case of the longer rivets, the longest driven in any bridge, the ends of the shanks were quenched to black red before driving, otherwise the head would have been formed

before/

before the rivet staved in the hole and filled it. All rivets were tested after driving to determine if they completely filled the hole.

The hydraulic pressure for the riveting machines was provided by two, three-throw hydraulic pumps, with an accumulator working at 1,500 lbs. per sq. inch.

The 80-ton machine was capable of driving a rivet $1^{13}/32$" in diameter and having a maximum grip of 12 inches.

The heavy fabricating or assembly shop was served by two overhead cranes of 120 tons' capacity and 147 ft. span. One was equipped with a 50-ton auxiliary and the other with a 25-ton auxiliary.

Transfer of partly completed material from the light shop was effected on bogie trucks running on two tracks, one from each bay. The partly fabricated material was loaded on the trucks and pushed from one shop to the other.

At the western end of the shop were two hydraulic riveting machines of about 80-ton capacity mounted on travelling gantries.

Assembling or boxing of all members of the arch, with the exception of a few laterals, was carried out in the heavy shop.

Each chord consisted of four web plates with a pair of angles riveted to the top and bottom of the web plates, 16

angles/

angles in all, to which the top and bottom flange plates were secured. Each chord was made in two pieces, which were stitched together by rivets through connecting plates 10 ins. wide.

In the case of chord members, one web was laid down in a horizontal position and the two flange plates secured in a vertical position by means of bolts or pins through the flanges of the angles which had been riveted to the webs by the hydraulic riveter in the light shop.

In this condition the plates were riveted to the web, the rivets through the upturned angles being driven by hydraulic machines and those through the lower angles which could not be driven in this manner, were driven by pneumatic air operated hammers, known as rattlers from the noise they made.

Then the other web forming the complete box or half member was placed in position and secured with bolts and pins.

On completion of the riveting, the half members were "stitched" together by pinning and bolting the 10 ins. stitch plates on each flange and then transferred to the end planing machines.

Ending:

Two planing machines were installed in the heavy fabricating shop. The smaller one was used principally for machin-

ing the/

ing the lighter members, such as, top chords, posts, diagonals and some lateral flanges, it had a rotary head in which the cutting tools were fixed, and was capable of end planing a member 12 ft. long by 4 ft. wide.

The other, the wall planer, specially built for the Bridge, was used for ending the very heavy chords and for the cross-girders of the first three panels, and had a single cutting tool with horizontal traverse and vertical feed capable of end planing a member 12 ft. by 10 ft.

The tool cut from the bottom to the top of the member about 3/16 in. vertical each cut with a depth of cut about 1/8 of an inch, the depth of final cut adjusted to give the exact length of member required. In the planing of one of the heavy sections the cutting tool travelled a distance of about 3 miles.

The setting up of all top and bottom chord members and cross-girder sections, for end planing was checked by the Department's Engineers for level and alignment by means of dumpy level and theodolite.

After ending and prior to assembly with the adjacent section the ends were thoroughly cleaned by wedging the plates and angles apart, filing off burrs and then blowing out any shavings with compressed air.

It/

It was during the process of machining that the correct length of each member was marked off, and the accuracy of this work was guaranteed by the close inspection at all times.

A record of the length checks taken on all truss members was kept in the Shop Inspectors' office by the Inspectors, and the information marked on diagrams of each truss. The difference between actual and plan lengths for each member and also the sumulative errors to each panel point were recorded.

The maximum cumulative error at any stage was 5/16 in. "long" in the case of the ninth panel of the south-west half truss. This error was gradually eliminated by compensating in the succeeding four panels.

The total length of the bottom chord between the pin centres is 1,830.7294 ft., the total length of the top chord between the intersection points of the end posts being 1,723.1756 ft.

A summary of the length checks shows that the entire bottom chord of the eastern truss was 3/32 in. shorter than the length as given on shop plans, while that of the western truss was 1/32 in. short. The entire top chord of the eastern truss was 1/16 in. longer than shop plan length and that of the western truss 5/32 in. shorter than length according to plans.

In/

In order to maintain an even temperature in the members being machined, portion of the side of the shop adjacent to the planing machine was covered with galvanised iron sheeting. This prevented any direct sunlight falling on the member and both outer webs were at approximately the same temperature when marking off for the finishing cut.

Expansion and contraction of the members during ending operations did not affect the end being machined for this was securely fastened to the bed plate of the end planer while the remote end rested on narrow packs.

The average range of temperature in the shops was 15° Fah. during the day shift and 18° during the full day of 24 hours.

Effect of Temperature:

With a coefficient of expansion of .0000061, the increment of expansion per 100 ft. for a temperature range of 100° Fah. was nearly 3/4 in. Therefore, say, a difference in temperature of 12° Fah. between an outer and an inner web in a chord web 60 ft. long would mean a difference in length of 54/1,000 inch, about 1/16 in. The maximum opening allowed on butts in the shop assembly was 4/1,000 inch, which shows the perfection of work required by the inspection.

The steel tapes used were periodically checked with the standard set down by the Department on the template floor and

all/

all measurements were made with standard tension of 15 lbs. in the tape. Furthermore, by means of small brackets fitted with rubber suction pads, the tape was supported at short intervals and allowance for sag was unnecessary.

All shop assemblies of chord butt joints were gone over with feelers to ascertain the condition of the butts. A maximum error of 4/1,000 in. only was allowed, and this only on the flange angles, the butts of the web and flange plates being in all cases in 100% contact.

At points where the butt was open, the Inspector marked the amount necessary to be filed off, which was done on dismantling and the butt at these points made satisfactory.

During this inspection all holes were examined and marked for opening out to a larger diameter where necessary.

It can well be understood that on these huge layouts, with drills drilling right through from the top webs to the bottom, riveters passing red hot rivets through the confined spaces in the chord boxes, the floor of the chord strewn with sharp drillings, that this work was strenuous for the Inspectors and men alike, who worked at no little risk of being burned by the hot scale from red hot rivets, and their knees cut by kneeling on sharp drillings in the confined spaces, their torches providing the only effective light for this work. A suit of overalls on this work lasted about two months.

The/

The necessity for accuracy and thoroughness in these measurements on shop assembled joints and lengths of bridge members, is apparent when it is realised that upon it depended the equal distribution of the stresses throughout the four web members and flange plates and angles of the chords as assumed in design. It also governed the level, alignment, etc., which the structure as a whole assumed when erected, and within what limits of accuracy the two half-arches met at the crown.

All truss intersections were assembled in the heavy shop and the rivet holes in the ends of posts and diagonals meeting on the main gussets were drilled under size and were opened up to full size when the members were placed in their correct angular relationship to one another around the panel point.

The method adopted in checking the angular relation between the chords, post and diagonal in a shop assembled joint was to set up a theodolite over the intersection point of the centre line of the members. Then with one chord member as a base, the correct position for the centre line of each of the other members was transferred by plumbing down over the end of the member to plates fixed on the floor of the shop. The Shop Foreman could then move the members into their correct position with the overhead cranes after which the layout was again checked and passed.

With/

With the aid of a dumpy level, the level of the whole layout was adjusted to bring all the members in a true horizontal plane. Then the distance from the intersection point to the butt joints in the diagonal and post were measured, adjustments to preserve the correct landing in the butt splice if necessary being made by moving the member in or out of the gussets along its centre line and the position of the machined and marked.

When the work was passed as satisfactory the holes in the gussets were opened to full size and the tie plates riveted to the flanges of the post and diagonal, which were later removed to the rotary ender and the butt machined to the correct length.

The procedure in checking these shop assembled joints of the Main Span was briefly as follows:-

The Shop Inspector first established the point of intersection from the drawings, working in conjunction with the Contractors' Leading Hand.

The theodolite was then set up accurately on this intersection point of the chord, and the several Bridge members forming the joint were moved by the shop cranes into their correct angular relationship.

An Officer of the Inspection Staff, either Mr. Litchfield, or Mr. Holt, and an Officer of Dorman, Long & Co's. Staff,

usually/

usually Mr. Lawrence, would remain by the theodolite until mutually satisfied that the angles were correct.

The layout was then passed for reaming of the holes.

All steelwork which was part of the finished structure was weighed before transfer to the field.

Two weighbridges with a capacity of 80 tons and 60 tons respectively were used and were checked periodically by the Inspector of the Weights and Measures Department.

Care was taken that all tares, such as timber supporting grillages, lifting gear, packs and all service bolts were deducted. In the case of the first five panels of the top chord the tare of straps on the temporary erection plates was also ascertained by the weighman.

The weight of field rivets was also taken and the quantities checked against field rivet lists and drawings in the office at the workshops.

The weight of the steelwork depending from the southern cables just prior to the arch meeting at the centre was 13,924 tons and from the northern cables, 13,928 tons, a difference of only 4 tons.

In the eastern end of the heavy shop, a dock was constructed from which the fabricated material for delivery to the field on either side of the Harbour was loaded direct on to a

punt/

punt in the dock by the overhead travelling cranes, and then towed by tugs to the pontoons moored below the creeper cranes erecting the half-arches. The punt was 110 ft. long, 24 ft. beam and had a draught of 4 ft. 6 ins. under a load of 120 tons.

The monthly tonnage fabricated varied considerably with the nature of the work in hand and the number of men employed.

The highest total reached during the fabrication of the Approach Span steelwork was 1,117 tons in August, 1927, when there were approximately 400 men employed.

In July, 1930, 2,281 tons of steelwork for the main span were fabricated, 754 men being employed in the shops at that time.

Three shifts were worked in the shops beginning May, 1927, to expedite the fabrication of the Bridge.

When in London in 1924, the shops and their equipment and the method for fabricating the work was fully discussed with the Contractors and approved by me, as complying with my requirements.

The shops and their equipment were designed by Mr. Ennis, O.B.E., Director of Construction for the Contractors, and were the most up-to-date bridge fabricating shops in the world; many of the machines being specially built for the work.

Mr. Henry/

Mr. Henry Martin was the Shop Superintendent.

On my Staff, Mr. Litchfield, B.E., Supervising Engineer, Mr. Holt, B.E., and the various Inspectors were responsible to me for the supervision of the fabrication of the Bridge. I set the standard to be observed, and the extreme care with which the work was supervised and checked was largely responsible for the facility with which the steelwork was erected in the field. Nothing was left to chance, the methods for checking were all carefully planned out, the butting of the chord joints in the arch were as perfect as it was humanly possible to make them. To plane the ends of the two chords 11 ft. wide and 8 ft. 9 ins. deep, each having sectional area of 2,700 sq. ins., so that they butt perfectly over the whole area is a triumph of mechanical skill and reflects the greatest credit on the Contractors, their workmen, and on the standard of inspection I required and obtained.

My Specification stated --

> "The workmanship and finish shall be the best that the most suitable modern machinery and skilled labour to be obtained can produce."

When sending my final report, to the Government, I can truthfully say that it has been so.

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THE SYDNEY HARBOUR BRIDGE.

Main Bridge -- Erection of Superstructure.

The erection the Approach Spans was commenced on 28th October, 1926, and completed during February, 1928, taking approximately 16 months to erect, and did not present problems of any undue magnitude.

The timber trestling on which the approach spans were supported was erected by 5-ton steam locomotive cranes, which moved forward over the falsework as it was erected. At the landward end of the approach, a 25-ton electric crane was erected on the trestling. This crane, working towards the Harbour, erected the steelwork of the approach spans on the falsework in front of itself.

While the Approach spans were being built, the abutment towers on either shore were constructed, so that the Harbour end of the adjacent approach span when completed could be supported by the back wall of the abutment tower.

When the 25-ton cranes had completed the steelwork of the approach spans, they constructed the steel deck above the abutment towers. The erection of the pylon steelwork on the south side was completed by 28th April, 1928, the north side being completed on 22nd January, 1929. The cranes also erected the steel ramps which supported the creeper cranes, the top

surface/

surface of the supporting ramps correspond with the level and plane of the top chord of the arch.

One ramp only was provided, it was first erected on the south side, and after the creeper crane was seated on the top chord on that side, the ramp was dismantled and re-erected on the northern pylon.

The erection scheme proposed for the Main Arch had to be submitted by the Contractors with their tender, but various improvements in the scheme were effected when the details were under final review. The erection of the Bridge has been achieved by a scheme bold and unique which reflects the greatest credit on the Director of Construction, Mr. Ennis, who carried the responsibility for the Contractors, also on their Consulting Engineers, Mr. Freeman and Mr. Imbault. The Victoria Falls Bridge across the Zambesi River was erected some 25 years ago by a very similar scheme devised by Mr. Imbault. The Tyne Bridge of 500 feet span was, subsequent to the acceptance of the tender for Sydney's Bridge, erected by Dorman, Long & Co. by a method identical with that adopted here, and gave the Contractors experience of the work to be accomplished in Sydney.

As proposed in their tender, the abutment towers, which then had vertical Harbour faces, parallel and adjacent to the

end/

end posts of the arch, were to be built up to a sufficient height to support the decking near the end posts. On this decking a stage was to be erected, the top surface of the stage corresponding with the level and slope of the top chord of the arch. The creeper cranes were to be erected on this staging and were to move forward to the first panel of the arch when it had been erected. The anchor tunnels were to consist of two shafts 10 ft. x 6 ft. interconnected by two semi-circular tunnels sunk to a depth of about 120 feet below ground level. Cables were to be connected to the tops of the end posts and were to be so arranged as to put a definite pressure on the rock where the cables reached the ground surface. The creeper cranes of weight 536 tons were to build out the first six panels of the arch, and the cable system was then to be readjusted, the final supporting cables were all to be attached at the fifth panel point and pass over tall struts seated on the tops of the end posts, whilst the cables previously attached at the ends of the vertical end posts to allow the six panels to be erected were to be then slackened off and removed. Additional cables, as required, were to be added at the fifth panel point as erection proceeded. After ten panels had been erected on either side, the two creeper cranes, each weighing 536 tons, were to be

dismantled/

dismantled and replaced by two lighter erection cranes each weighing 180 tons, to erect the eight centre panels, and the hangers and cross-girders of the deck. The final adjustment and the meeting of the lower chords at the centre was to be brought about by operating a toggle gear situated on the top of the abutment towers.

Tenders were received on January 16th, 1924, my report on tenders was submitted one month later, on February 16th, but within a few hours after tenders had been received, it was evident to me that only two firms had tendered in accordance with my Plans and Specification, and that Dorman, Long & Co's. tender was the lowest. I spent the major portion of the month in investigating their proposed scheme of erection, which, on a lesser scale had then been successfully tried out in erecting the Victoria Bridge over the Zambesi River; at the date I reported on tenders, the Tyne Bridge was only a proposal. I was satisfied the arch could be erected by the scheme proposed and took the responsibility of recommending Dorman, Long & Co's. tender for acceptance. What that responsibility meant may be gauged by the fact that at the time of closing the arch, the Government had paid £3,031,227 on the Contract, whilst the retention money by the Department from the Contractors amounted to £430,000. Had the Bridge

collapsed/

collapsed, as almost everyone freely predicted it would, Dorman, Long & Co. were bound to replace the Bridge at their own expense, under the terms of the Contract. I would certainly have been replaced, disgraced, but the State of New South Wales was fully protected as far as it was humanly possible legally to do so, by Clause 20 of my Specification, specially devised for that purpose.

The securing of the cables at the fifth panel and passing them over a tall strut on top of the end post, itself 190 feet high, was, in my opinion, an element of risk, for every time a sudden change of temperature occurred there would be nearly always as a consequence, a heavy gale, wracking the cable connection over the supporting strut.

Moreover, the dismantling of the heavy creeper cranes at the tenth panel and replacing them by lighter cranes, would have stopped construction for probably three months, and the arch during that period would be subjected to every storm which might occur.

In April, 1926, Mr. Ennis and Mr. Freeman, who was then in Sydney, asked to have the scheme of erection revised, proposing the alterations to the scheme as finally carried out, the principal alterations being the attaching of the cables at the ends of the top chords not at the fifth panel, also the

provision/

provision of two creeper cranes only for the erection of the arch, in lieu of the four cranes as submitted in the tender, two of which had to be dismantled, and by doing away with the toggle gear for meeting the arches at the centre. I told them that, as a result of my investigations, made over a period of two years, since the Contract was let, I was in thorough accord with the revised scheme, as it did away with an element of risk, but it meant a greater outlay for the Department, in that more material required for erection purposes only, would have to be incorporated in the top chord of the arch, and as this could not be removed after erection was completed, under the terms of the Contract it would have to be paid for. Final plans show this quantity of additional erection material to be about 700 tons. The Contractors were put to greater expense on account of the improved cable system and grester number of cables, but also were saved the cost of the lighter cranes and their erection and dismantling. All details were fully discussed, and were verbally approved by me as they had to be under the terms of the Contract, before any alteration in the erection programme could be undertaken by the Contractors.

The erection of the arch was commenced on the south side

on/

on 26th October, 1928, and completed on 15th September, 1930, taking one year and ten months to erect.

The heaviest lift in the arch was the lower chord in the sixth panel, viz., 112 tons. This member was the first lower chord to be erected in its entire length, viz., 66,288 feet.

The main arch was erected by cantilevering out from each shore, the structure being held back by 128 wire cables attached at the tops of the end posts.

The scheme of erection in the early cantilever stages consisted of attaching numbers of cables to the tops of the end posts to balance the arch, the number of cables being increased as the load on the arch increased. The solid mass of the abutment tower formed a support for the temporary raking strut between the top of the end posts and the top of the abutment tower, against which the cables strained back.

This "temporary raking strut" rigidly supported at its base, formed a steady support for the arch, and enabled the stress per cable to be considerably increased in excess of the amount necessary to balance the arch; the frictional resistance of the cables round the tunnel face was thereby increased, and the possibility of the cables slipping in the tunnels under the action of wind and temperature on the structure became negligible.

For/

For the first few panels of the arch it was impracticable to use temporary sway frames at each vertical, as was done later, and if the arch had only been hanging from cables without the racking struts, the relative deformation of one arch truss in regard to the other when the jib of the creeper crane was traversed and a heavy member lifted directly over one truss, would have been sufficient to produce heavy bending stresses in the bottom lateral bracing, sufficient to bring about collapse of the structure. Many of the members lifted in the first few panels of the arch weighed about 100 tons; the main jib and its carriage, with the member lifted, weighed about 400 tons, a heavy eccentric load. By means of the rigid support formed by the raking struts, the deformations were reduced to a minimum, and the lateral members were not over stressed in bending.

The raking strut with its rigid base was vital in the early stages of the erection scheme, and without the rigid support formed by the abutment tower its use would have been impracticable.

The cables required for the anchorage were threaded into position round the cable tunnel, through the tunnel saddle and pylon saddle, and the free ends were laid over the front wall of the abutment tower. Each cable is 2.76 inches in diameter

approximately/

approximately 1,200 feet long from end to end, and is made up of 217 wires, one centre wire .20 inches diameter, and 216 wires each .16 inches diameter. The ultimate strength of a cable is 360 tons as a minimum; the final load carried per cable was 125 tons. The cables were prepared for attachment by cutting to the correct length and fitting with a cast steel socket. To connect the cable to the socket, the cable was passed through the socket, the wires were opened up and cleaned, some wires being bent over at the ends, and the socket forced upwards on the cable until the opened wires filled the bell-shaped mouth of the socket. The whole of the socket, with its contained wires, was heated by blow-lamps, and molten white metal of composition lead 86%, antimony 11%, tin 3%, was then poured into the socket. When solidified, the socket connection developed a greater strength than the ultimate strength of the cable itself. All socketing of cables was performed in sheds erected on the end of the pylon cross-girder.

The final anchorage consisted of 128 cables, arranged at the end post in eight horizontal rows of 16 cables each; the cables had two 3-inch bolts per cable, fitted with special thread, nuts, and spherical-seated washers; the bolts passed through the socket flange and on either side of pins 11 inches in diameter, grooved to allow the passage of the bolts. At

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the back end of the pins, the bolts passed through a rectangular forged steel saddle, and projected beyond the saddle a sufficient distance to allow the nuts to be slackened off when the cables had to be removed after the arch had met at the centre. The eight 11-inch diameter pins were seated in large fan-shaped built-up steel link plates, five links in each set, which sets in pairs were connected to the top chord by means of two pins 27 inches in diameter, each 6 ft. 1 in. long. The pins passed through holes 27 inches diameter in the webs of the top chord, which were heavily reinforced by pin plates. The weight of the link plates was taken by the joist on the end of the end post bracket.

As the erection proceeded, panel by panel, only sufficient cables were attached and tensioned up to balance the arch and to ensure that the permissible load on the raking strut would not be exceeded under changes of temperature. Eventually, at the seventh panel, the whole of the 128 cables were in action, and the raking strut was no longer required.

When attaching cables, first the anchor bolts and saddles were put in position, and the cable socket was threaded on to the ends of the bolts to a calculated distance, so that the stress in each canle was about 10,000 lbs. In order to tension up the cables, hydraulic jacks were used, operating on

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the back ends of the bolts behind the saddles. The jacks thrust against a cross-head bolted on the ends of the bolts and pushed back against the saddle, so that the nuts on the saddle were relieved of stress. When tensioning, the whole cable was jacked up in this way, the bolts moving through the saddle, and the nuts were turned by hand following the movement of the jacks, until the desired load was in the cable, as measured by the pressure gauge on the jack.

The tension was checked from time to time by vibrating the cables over the length of 133 feet between the end post and pylon saddle. According to the properties of the cables, its span, weight per foot, etc., the stress in the cable is related to its rate of vibration per minute. This formed a check on the equal distribution of load in the cables.

The heavy members of the first panel on the Dawes' Point side were landed within reach of the creeper crane by the "Titan" floating crane.

The first member lifted into place was the section of the first panel of the lower chord adjacent to the western bearing at Dawes' Point. This member was put in place on the 26th October, 1928. It weighed 88 tons. The arch trusses were completed on September 10th, 1930.

The corresponding member of the eastern truss at Dawes'

Point/

Point was placed in position on 7th November, 1928.

The arch was cantilevered out, panel by panel, the cables supporting the steelwork as it was built out.

When 13½ panels had been erected on each side, the weight of steelwork in each half-arch was 13,670 tons, supported by 128 cables, the tension on each cable 107.2 tons, the total pull on each system of cables being 27,440 tons, and the thrust on each of the four main bearings being 17,660 tons.

To offset the stretch of the cables and the deformation of the structure as erection proceeded, and to allow a sufficiency between the lower chords for the meeting on the centre pins, the end posts of the arch were set back at the top with a rake of 30 inches from the vertical. At the completion of the cantilever stage of the two half-arches of 13½ panels each, this backward rake was reduced, by the stretch of the cables and the deformation of the structure, to 18 inches on the south side and 14 5/8 on the north side; the gap between the ends of the lower chords at the centre to allow for the meeting of these chords on the centre pins was 31½ inches on the east, and 31 5/8 inches on the west side. These gaps were affected by temperature and could have been 4 ft. 3 ins. at minimum temperature due to constructions of the cables and steelwork, and 1 ft. 9 ins. under maximum temperature conditions, due to

elongation/

elongation of the cables and steelwork.

On 7th August, 1930, the bottom chord of the fourteenth panel of the northern half-arch was erected and a short plank gave access across the Harbour for the first time. Mr. Ennis, Director of Construction for the Contractors, was the first person to walk across the gap at the centre of the arch, and Mr. Holt of my Staff was the first person to cross from shore to shore.

Both half-arches were finished off identically at the centre joint, the lower chord on each side was fitted with a heavy forged steel saddle to enclose a pin 8 inches in diameter. Before closure was commenced, the 8-inch pins were screwed into the saddles on the southern side, and to provide for the half-arches being out of alignment horizontally and vertically, lateral adjustment was provided by means of 10-inch square locking bolts.

The half-arch on the southern side weighed 13,924 tons and on the northern side 13,928 tons, a difference on only 4 tons, which is an indication of the care exercised in rolling the plates and sections.

The fabricated steelwork of each lower chord at the centre joint was machined to receive the steel forgings which enclosed the centre pins, 8 inches in diameter.

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On the northern half-arches, each steel forging was carried by two of the four web plates, and between each forging a heavy steel diaphragm was built, having an opening 10 inches square, into which the locking bolt from the truss opposite could engage.

On the southern half-arches the 8-inch pins in two lengths were set-screwed into the steel forgings, and the locking bolt, 10 inches square with tapered point, was placed in the centre between the two 8-inch horizontal pins, and could be thrust forward by an hydraulic jack into the opening of the diaphragm, which would bring the opposite half-arches into line and level.

To close the gap of about 31½ inches between the half-arches, the nuts on each pair of link bolts connected with a cable were run forward one by one in successive fleets of 3 inches, 4 inches, 5 inches and 6 inches respectively. A fleet forward of 3 inches at each end of the arch closed the centre gap by nearly 12 inches.

Each cable was adjusted independently by means of a high-pressure jacking equipment working up to a pressure of 4 tons per sq. inch; and to ensure that each cable was let out the exact amount determined on for each fleet, special gauges were used to measure the distance the nuts had to be moved back on

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the 3-inch link bolts.

For the first three fleets the hydraulic jacks operated against the back face of the saddle and pushed the 3-inch bolts upwards by thrusting against a cross-head attached to the ends of the bolts. For the later fleets, extension bolts were fitted over the ends of the 3-inch bolts when the outstanding length of these was too short for the jack.

The work was carried out in two twelve-hour shifts until contact was made on the centre pins, which took place after the first and the second fleet of 3 inches and 4 inches respectively had been completed on all the 128 cables at each end of the Bridge, and the third fleet of 5 inches was in progress, 37 cables being let out on the north side and 55 on the south side.

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THE SYDNEY HARBOUR BRIDGE.

Main Bridge -- Erection of Superstructure
Part Two.

At 11 a.m. on the 19th August, when the gap was 4½ inches between the eastern and 4¾ inches between the western lower chords, the locking bolts were forced home by the hydraulic jacks, to bring the half-arches into correct line and level. Immediately prior to the jacking, the half-arches -- mostly caused by temperature -- were about 3½ inches out of line horizontally and 2 inches vertically, the sun influencing the half-arch and cables on the northern side more than on the southern and the eastern truss very slightly more than the western truss.

The fleeting forward of the nuts was continued until, at 10 o'clock p.m., August 19th, at a mean temperature of 62° Fah., full contact was made on the pins. Messrs. J. A. Holt, B.E., and G. A. Stuckey, M.E., of the Sydney Harbour Bridge Branch were at the centre when contact was made. The circumstances proved ideal, as the temperature continued constant throughout the night, until it began to increase with the sunrise, which ensured that the half-arches did not draw apart, as would have happened had a fall in temperature caused the cables to contract. Once full contact was made, as the slack-

ing of/

ing of the cables continued, the half-arches bore on the centre pins with an ever-increasing intensity.

The arch was now in a three-hinged condition except for the residual tension still in the anchorage cables; the rake-back of the end posts at this stage had been reduced to $5\frac{3}{8}$ inches on the south and $5\frac{5}{8}$ inches on the north side; the half-arches had dropped 4 ft. $1\frac{1}{4}$ ins. at the centre, due to the fleeting forward; immediately prior to meeting, the centre pins were 348 ft. 6 ins. above the level of the centre of the pins in the main bearings at the abutments.

The third, fourth and fifth fleets of the nuts were completed when the tension in the cables was reduced sufficiently to admit of their being detached from the link plates at the ends of the top chords.

This was carried out by means of a special frictional gripping device attached to the cables some 20 feet behind the arch, and then by pulling on this grip with the 25-ton crane through a heavy block-and-tackle purchase, and working in conjunction with the hydraulic jacks, the cable bolts were released from the link pins, and the cables were allowed to slide back until the socketed ends rested against the pylon saddles.

When this operation was completed at one set of link

plates/

plates, there was practically no tension at the other end of each cable, which was removed from the link plates and run down to the pylon saddle by means of a light electrically-driven winch.

Whilst the cables were being disconnected from the link plates, the erection of the centre posts, top chords and top lateral bracing of the fourteenth panels was undertaken.

During the erection of the half-arches the structure consisted of two cantilevers, in which the top chords were in tension. In order to withstand the high-tension erection stresses, the four vertical webs of the top chords of the first five panels were strengthened by means of additional plates attached thereto by specially fitted pins and bolts. The weight of this additional erection material was 798 tons.

Before the final jacking operations were undertaken to change the arch from the three-hinged to the two-hinged condition, it was necessary for each member of the arch to have its final effective section, so that, while the cables were being disconnected, the pins and bolts connecting the temporary tension plates in the five end panels were driven out, to that the temporary erection material would not take any of the jacking stress.

The arch was converted into the two-hinged condition by jacking the top chords apart at the centre top chord joint.

The permanent joint at the centre of each top chord

consists/

consists essentially of four forged steel saddles enclosing two pins, each 10 inches in diameter. The saddles and pins were hung in the gap between the chords in a special frame before the four hydraulic and eight screw-jacks were assembled. As the force was applied by the hydraulic jacks, the screw-jacks, were made to follow up the motion, as the gap between end plates of the chords opened out. The difference between the overall width of the permanent saddles and pins, and the distance between end plates of the two chords after jacking, was to be made up by parallel fitted filler packs measured off and machined out of forgings provided for the purpose.

The calculated thrust depended upon the elasticity of the structure, the loads upon it, and the temperature of the structure. The members of the arch had to be brought into their proper elastic condition, and to effect this the temporary reinforcing plates in the first five panels of the top chords on each side were disconnected; as the cables were being removed, the tension in the chords was relieved sufficiently to allow this to be done.

The cables were removed as rapidly as possible, careful note was made of the load imposed on the structure by the erection equipment, and thermometer stations had been established at twenty-four points throughout the structure. Meanwhile, the jacking equipment was assembled in the space

between/

between the ends of the top chords at the centre.

This consisted of four hydraulic jacks, each 950 tons' capacity, two operating near the top and two near the bottom flange of each top chord. Each jack was made of 3 per cent. nickel steel, 2½ inches thick, and worked at a pressure up to 4 tons per sq. inch. Two screw-jacks were placed alongside each hydraulic jack to follow up the movements of the latter, eight hydraulic and sixteen screw-jacks being employed in all for the jacking. The screw-jack consisted of a central cylinder into which left and right-hand buttress-threaded rams were screwed. By rotating the central cylinder with capstan bars, the required movements were obtained. The hydraulic pressure on each truss was supplied from two hand-operated pumps with the necessary gauges. Each jack and gauge had been calibrated in the 1,250-ton testing machine provided by the Contractors under the Specification for testing model members for the Bridge

On Monday, 8th September, the cables had been all removed except 37 on the southern side and 15 on the northern side, and some of these were hanging slack. The day was cloudy and extraordinarily well suited for the performance of the final jacking operation, on account of the even temperature and the extremely small variations in the temperature of the various members of the structure as indicated by the 24 thermometers. It was accordingly decided to perform the

jacking/

the jacking before the remaining cables were released, as the possible error involved in the calculation of the effect of the pull of the cables was less than that which would have been caused in determining the mean temperature and its effect had no such perfect temperature conditions prevailed. The jacking force, as calculated for a temperature of 60.5° Fah., was 3,272 tons per truss, corrected by 22 tons for the cable effect, and so at 5.15 p.m. the 3,250 tons force was applied by the jacks to each arch truss.

During the operation the chords were forced apart a total distance of about 5½ inches. The total gap on completion of the jacking was $29^{9}/16$ inches on the eastern truss, $29^{25}/32$ inches on the western truss. The space occupied by the saddles was filled with fitted packs in pairs. These were machined to size, and on the morning of September 10th, the packs were fitted in position, the load on the jacks released, and the jacks removed.

From the time the lower chords met on the 8-inch pins until the top chords were jacked up and all cables removed, the centre of the lower chord rose upwards a distance of 1 ft. 1½ ins., the elevation of the centre pins at a temperature of 65° Fah. being 349 ft. 7½ ins. above the level of main bearing pins. With total dead load the structure should

assume/

assume its geometrical form; the elevation of the lower chord centre joint should be 350 ft. above the level of the main pins at a temperature of 72° Fah.

Both cranes were altered slightly at the back ends of the jibs to allow of a shorter minimum reach, and the cranes were then ready to commence the return journey down the top chords, erecting the hangers and steel deck.

There are 42 hangers in all, varying in length from 191 ft. 10½ ins. at the crown to 21 ft. 1 3/8 ins. at the first suspended cross-girder. Each hanger was erected by the creeper crane on the top chords of the arch, but the lifting was complicated by the necessity of entering the top end of the hanger into gusset plates on the bottom surface of the lower chords, which are 11 ft. 0 ins. wide overall.

The long slender nature of the hangers to be lifted from a horizontal position on the pontoon in mid-stream made necessary the use of a substantial steel cradle to give intermediate support to the hanger. The hanger was placed on the cradle in the fabricating shops and placed in position on the pontoon. The cradle was fabricated from portions of the steel ramp structure on which the creeper cranes were erected before travelling on to the top chords of the arch, and weighed 55 tons. The heaviest hanger weighed 37 tons.

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The cradle consisted of two plate web girders braced together and provided with a head end for the main hoist, and a horn bracket 20 ft. 8 ins. long, to support the hanger and to give a purchase for the jigger hoist of the creeper crane for tilting. The overall length of the cradle is 110 ft. $7^7/8$ ins. At the head end the upper end of the hanger was secured by a 6-inch diameter pin passing through pin-holes bored in the tie plates of the hanger. The lower end of the hanger rested in the U of the horn bracket when in the horizontal position.

In the shops the cradle and hanger were hauled by the 125-ton overhead crane attached to V-links near the centre of gravity of the hanger. The hoisting arrangements in the field consisted of a special link attached to the main 122-ton hoist of the creeper crane. From this link a bridle made of sections of the arch anchorage cables and U-bolts was connected to $7\frac{1}{2}$ in. diameter pins in the head end of the cradle $10^7/8$ ins. above the top flange of the cradle girder. For tilting into a vertical position, the 20-ton jigger hoist was connected to a bridle with a double purchase between the hoist link and the pulley wheels on the top of the horn bracket. The main hoist and jigger hoist travelling at the same speed ($12\frac{1}{2}$ ft. per minute) lifted the top end twice as fast as the

bottom/

bottom end, until the hanger became vertical.

When the hanger was vertical, the jigger hoist was slackened off, and the cradle took up a position such that the hanger was balanced vertically but offset about 9 ft. 6 ins. from the line of the main hoist. The whole was then swivelled round at right-angles so that the hanger was in position immediately under the lower chord. From this position the top end of the hanger was entered into the gussets.

When the first pair of hangers were in place, the centre cross-girder was hoisted from the pontoon by both cranes, each crane hoisting one end of the girder. The weight of the main cross-girder was 95 tons. For subsequent cross-girders, one crane only could be employed, lifting from the centre of the girder.

As three sets of hangers and cross-girders were completely erected, forming the two central panels of the deck, all the steel stringers, joists, handrails and trough plates were hoisted by the creeper cranes and fixed in position complete. The deck was erected in this way, panel by panel, on both sides of the centre, until the creeper cranes regained their original situation on the end panels of the arch.

The 25-ton cranes which had originally erected the approach spans were set up on timber gantries to dismantle the

creeper/

creeper cranes, and then were themselves taken down by 7-ton cranes erected on timber trestles for the completion of the pylons.

Deck details now remained to be finished. The pipe handrails on the parapets were fitted into place throughout the length of the Bridge, and overhead wiring structures were erected on approach spans, pylons and main span.

Coke concrete was poured in the steel troughs of the roadway deck, and for a thickness of 4 inches above the troughs. The concrete was poured in three strips, commencing on the Northern Approach spans, then the Southern Approach spans, and the main span working from the centre.

The coke concrete was of a type specially developed by me for the Bridge, using metallurgical coke from the South Coast and high-strength cement. On account of the large span of the arch, every pound per foot run of dead load of Bridge requires half a ton of steel in the Bridge to carry it, so that lightness was an essential feature of the concrete.

After an exhaustive series of tests, the composition and grading of the coke concrete was finally determined. The concrete consists of 4 parts of metallurgical coke, $1^1/8$ in. in size down to $^3/8$ in., $2\frac{1}{2}$ parts of fine coke, from $^1/4$ in. size down to dust, and 1 part of special cement, giving

7,000 lbs./

7,000 lbs. per sq. inch crushing strength when mixed with standard sand in a 3:1 mortar at 28 days. The laboratory tests of the concrete gave results of 3,000 lbs. per sq. inch crushing strength at 28 days. Some field tests actually cut out of the pavement gave 4,000 lbs. strength.

A pavement of natural rock asphalt, 2 ins. thick, followed closely behind the concrete, and asphaltic concrete on the footways, 1 in. thick above the troughs.

The completed roadway was now utilized as a working space for the timber decking on the railway tracks. The ironbark transoms and sleepers were dressed and lifted over the parapets, bolted in place on the steel stringers carrying the tracks, and followed by hardwood planking forming the decking between the rails.

Rails and guard rails were delivered on the roadway, with all permanent way material, sleeper plates, bolts and spikes, hoisted over the parapets, and spiked in position. The permanent way details call for rail expansion joints to take up the movements of the Bridge, the main joints allowing an expansion of 12 inches.

The rail expansion joint between approach spans, consists of a cast manganese steel expansion bar, bolted against the web of the rail on the outside, and projecting slightly on a

ramp/

ramp above the top of the head of the rail, part of which is cut away on the outside. The tread of the wheel is carried by the bar over the rail gap, the bar having slotted holes on one side for the purpose of allowing the expansion to take place. When the wheel has been carried over the gap, the ramp of the bar allows the true rail to take up the load. The car wheels will thus be carried over the rail gap smoothly, without any pounding. Heavy built-up checks guide the flange of the wheel past the joint.

The main span rail expansion joint is similar in principle to a switch, except that the switch can never open, but sliding motion is allowed between the fixed switch rail and the moving rail alongside. The switch rail is bolted down to a solid base plate by means of steel castings, similar castings provided a guide for the sliding rail. With this arrangement there is no gap to be traversed, and continuous smooth running is assured. Heavy built-up check angles ensure the alignment of the wheels passing the joint.

For the present, only two of the four tracks will be used for railway traffic, as the maximum number of trains passing over the Bridge in an hour will be 14 or 15, which can be easily dealt with on two tracks. Not until the traffic reaches about 40 trains per hour will the other two tracks be

necessary/

necessary for the trains. Cabinet has given a direction that trams as well as trains shall run across the Bridge. The trams will be carried on the two easternmost tracks, leaving the western pair of tracks for the railway traffic.

On the Approaches, the trams will be carried on the standard tramway permanent way, i.e., 80 lbs. rails and sleepers 4½ ins. thick. On the Bridge Contract the rails will be 100 lbs. per yd., the same as the railway rails, and the permanent way details are similar to railway details, modified to suit the smaller flanges of the tramway wheels.

The lighting fittings, overhead wiring and signalling arrangements are now in progress. The Bridge awaits only the completion of the pylons and the dismantling of the pylon crane gantries to allow it to be tested.

The Bridge will be thoroughly tested before opening for traffic, by means of 96 locomotives and 48 tenders, placed on the Bridge to develop the worst conditions likely to occur in regard to loading. After a full series of deflections and extensometer readings under the weight of the arch itself, the locomotives, weighing 8,280 tons, will be placed on the Bridge, covering all four tracks for a distance of 1,100 ft. over the centre of the main arch, and a further set of deflections and stress measurements will be performed. The most severe test

is that which follows, viz., to place the locomotives on all four tracks so that they cover one half of the arch span only, when deflections and stresses will be observed. The testing will occupy about four weeks in the month of February next, after which the locomotives will be withdrawn ready for the Opening Day on March 19th next.

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No. 13.

THE SYDNEY HARBOUR BRIDGE.

Northern Approach Construction

Travelling down the North Shore Line one can see where the railway tracks leading to the Sydney Harbour Bridge take off. Less than one hundred yards from the Milson's Point end of Waverton Station, on the left-hand side, is the viaduct where men have been seen busily engaged installing the automatic signalling, and completing the laying and ballasting of the Bridge railway tracks.

Crossing over a reinforced concrete arch bridge at Euroka Street and then under a reinforced concrete girder bridge over Bank Street the four railway tracks enter two double-track tunnels and after a journey of just over a quarter of a mile, emerge at North Sydney Station, situated in open cut -- that is, in an excavation made in solid sandstone of an average depth of about 25 feet. The distance from the centre of Waverton to the centre of North Sydney Station is 49 chains.

After leaving North Sydney Station, the railway tracks pass over viaducts and then we arrive at Milson's Point, 35 chains distant from North Sydney. This situation is the last before reaching the Bridge and is situated in front of the old

North/

North Sydney Town Hall, near Burton Street. About 100 yards further on and passing over Fitzroy Street, we come to the North End of Contract, that is where Dorman Long's Contract of 3,770 feet, or almost three-quarters of a mile of steelwork, begins.

From the junction with the existing lines near Waverton to the North End of Contract is a distance of 1 mile 14 chains and the construction of this piece of railway involves works of considerable magnitude, representing various examples of Civil Engineering, e.g., tunnelling, the construction of the railway Stations, North Sydney in an excavation and Milson's Point on a concrete and steel viaduct, a steel arch bridge of 220 feet span, five reinforced concrete arch bridges ranging from 50 to 120 feet spans, together with other concrete and steel construction.

That gives a very brief summary of the Northern Railway Approach, and I will endeavour to give my listeners an outline of the roadway and footway approaches before describing in greater detail the various features which combine together to form these approaches and which I know you will appreciate much better when you travel over them in March next.

The roadway approaches commence near the intersection of Walker and Junction Streets, where the Main Roads Board has

recently/

recently demolished the old Methodist Church in order to continue the Bridge Roadway to join the Lane Cove Road near the Post Office, and thus form a fitting commencement for the Pacific Highway. The Lane Cove Road has already been widened to 84 feet by the Main Roads Board. On the first section of the Bridge Highway, Junction Street is widened to 100 feet by setting back the western building line. This work has been completed as far as possible and travellers by tram to Milson's Point can see the widened portion. It cannot be completed until the Bridge is opened for traffic and the tramway ceases to connect with the Milson's Point Ferry.

Where Junction Street meets Alfred Street, McDougall Street and the Bridge Highway, there is a large traffic intersection. From here the Bridge Highway commences a rising grade and passing Milson's Point Station it reaches the North End of Contract which is 42 chains, or slightly more than half a mile, from its commencement at Walker Street.

The footways to the Bridge start from street level at Burton Street, there being one set of stairways called the Bridge Stairs on each side of the viaduct, marked by a granite slab inset in the concrete.

The particular parts of these approaches and the methods

of/

of constructing them will now be described.

The actual commencement of the construction of the Bridge and Approaches was made on 28th July, 1923, when Mr. Ball, M.L.A., then Minister for Public Works, turned the first sod on the Northern Approach at the site of North Sydney Station. Tenders had not closed for the Bridge, but this step was necessary in order to show prospective tenderers that the Government was in earnest, and also that vacant possession of the site of the old railway station at Milson's Point might be given to the Contractor within the shortest possible time after the acceptance of a tender. On the Monday following, 30th July, 1923, the office was installed in the house previously occupied by Dr. Gatenby at the corner of Blue Street and Walker Street near where the footbridge now is and work was commenced. After the many years of political thunder, the construction of the Bridge had really begun, and North Sydney re-echoed to the thunder of work as the gelignite shattered the rock in the excavations.

Properties were quickly demolished along Blue Street and in Bank and Euroka Streets. On account of the Sydney Harbour Bridge Branch not having the necessary plant at the time, and as it was imperative to have the goods station at Milson's

Point shifted to its new location as early as possible, a Contract was let to the State Monier Pipe and Reinforced Concrete Works for the construction of a 50 feet reinforced concrete arch bridge to carry the four tracks over Euroka Street and for the Bank Street girder bridge. The Contract price of these two bridges was approximately twelve thousand five hundred pounds (£12,500), and this was the first Contract let on the Bridge Approaches.

In January, 1924, the tunnelling operations commenced. The tunnels between Bank Street and Miller Street are a little more than a quarter of a mile long and enter the hill from the Bank Street end as two double line tunnels. Before reaching North Sydney Station each double track tunnel bifurcates and the tracks emerge as four single line tunnels in order to serve the two island platforms of that station.

The excavation for the tunnels is through solid sandstone of excellent quality; no timbering was necessary, although where the double track tunnels bifurcate the excavations were about 38 feet wide. The tunnels pass under "Graythwaite" and the Church of England Grammar School, the cover above the roof of the tunnels ranging from 20 feet to a maximum of 80 feet. Headings about 6 ft. by 6 ft. were driven ahead of the main

excavations/

excavations and as soon as it was practicable three shifts of tunnellers were at work. The material excavated by the two night shifts was dumped from the skips just outside the mouths of the tunnels and then picked up by steam navvies and loaded into lorries during the day shift.

One noticeable feature of the sandstone was that under the traffic of the construction lorries removing the spoil, it soon formed mud and cut into ruts when wet with water from the rock drills. Repeatedly the lorries became bogged in the tunnels and were extricated with difficulty until it became necessary to ballast a construction road with blue metal inside the tunnels on what had been the hard sandstone bottom of the tunnel.

The tunnels were lined throughout with concrete, the sandstone from the excavation being broken up and used in the concrete.

In building these tunnels, 80,000 cubic yards of rock were excavated at a cost of 22/- per cubic yard, 12/- representing labour charges and the balance the cost of explosives, disposal of spoil, etc. The cost of these tunnels was about 8/- per cubic yard cheaper than on the City Railway, as no timbering was required. The viaduct at the Bank Street end

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and one tunnel and the excavation for North Sydney Station were completed and one track opened for traffic on 26th March, 1925; the same day as the foundation stone was set on the southern abutment tower. This line was then used as a goods siding and has meant a large saving to the Department and to the Contractors, as all materials can be brought by rail to the vicinity of North Sydney Station. The layout of the tracks provides for terminating trains at North Sydney Station if desired.

North Sydney Station, situated between Miller and Walker Streets and fronting Blue Street, is wholly in cutting and has two island platforms. The station building fronting Blue Street features a spacious main entrance flanked by three shops on each side. The main walls and piers are finished in brickwork, the front elevation being relieved with tiled facings and fitted with a decorative awning for its full length. From the entrance landing a stairway is provided down to the concourse floor, the level of which is below that of the shop floors. The concourse layout provides for the various station offices, the lower portion of the walls being tiled, metal window frames being provided, ample provision is made for the natural lighting of the concourse and offices. The

tiling of North Sydney Station is carried out in a white groundwork suitably ornamented by bands of blue tiles. These are the colours of the North Sydney Church of England Grammar School, situated just above North Sydney Station.

On account of the Public School on the opposite side of Blue Street and as the trams will pass down Blue Street, a pedestrian subway has been constructed under the street to the station concourse.

The Contract for the steelwork of the station building and platform awnings, a total of about 250 tons was let to Walsh Island Dockyard.

It was not possible to keep Walker Street open for vehicular traffic, but a handsome reinforced concrete overbridge is provided across the railway tracks for pedestrians.

After leaving North Sydney Station, the railway tracks pass over a reinforced concrete arch bridge of 50 feet span over Arthur Street and then on a viaduct of heavy steel beams encased in concrete and supported on concrete piers. The space under these piers fronts the widened Junction Street, and, as the major portion of the vehicular traffic across the Bridge will pass up Junction Street, the area will be valuable for letting purposes.

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It was recently decided by the Government that two of the tracks across the Bridge will be used by trams until such time as the four tracks are required for railway purposes. The trams now going to McMahon's Point and those terminating at Milson's Point will be re-routed down Blue Street, and, connecting with North Sydney Station for the transfer of passengers, will turn on to the viaduct near the intersection of Junction Street and Blue Street and then run parallel with the railway tracks until Alfred Street is reached.

At Alfred Street, the railway and tramway tracks are about 40 feet above the roadway, while at the end of Contract they are on the same level. The two tramway tracks diverge from the railway tracks near Alfred Street, the former passing over the Bridge Roadway by the 220 feet steel arch bridge, while the railway tracks traverse a viaduct on the western side of the Bridge Roadway passing over the extension of Lavender Street by a reinforced concrete arch bridge of 120 feet span.

The 220 feet arch is the largest bridge on the Approaches, and is the only one constructed in steel; the long span being required on account of the skew angle of the crossing, the limited headway and the necessity of avoiding any piers on the

roadway/

roadway. Being on top of the ridge above Careening Cove, the aesthetics were considered to be of primary importance and the arch type was chosen with ornamental metal parapets. Massive concrete abutments are provided, simple and impressive in their design, and harmonising with the heavy steelwork and concrete approaches. There are two main girders of silicon steel each erected in seven sections of approximately 20 tons each. Clyde Engineering Company, the successful tenderers at a price of twenty-five thousand pounds (£25,000), recently completed the erection of the steelwork. The Bridge Branch constructed the heavily reinforced concrete deck now waterproofed and ballasted for the two tram tracks.

The concrete arch of 120 feet span over Lavender Street is the largest of the concrete arches of the Approaches and on account of its size the open spandrel type was chosen. It was imperative that the arch ring be poured in one day and special precautions were taken so that the work of placing the concrete should be continuous until completed. Although there were 47 tons of steel reinforcement in the ring and 488 cubic yards of concrete involving the handling of about 1,000 tons of material, the whole was successfully completed in one day. All the columns and deck, 345 cubic yards in all, were

also/

also poured in the one day. These very considerable yardages of reinforced concrete for one day's work show what can be done with careful organisation.

Between the steel arch and the Lavender Street arch is an area about 170 feet by an average width of about 25 feet, designed to be a garden, and in August last the wives, mothers and daughters, or members of the Bridge Staff, planted "The Grotto" with tree ferns and a number of Australian shrubs. Mr. Davidson, M.L.A., Minister for Works, and Mr. Howe, M.L.A., Member for North Sydney, took part in the ceremony, as did also Mr. and Mrs. Martin, Mr. Martin being in charge of the Contract during the absence of Mr. Ennis. A Queensland Pins, and two Moreton Bay Ash trees, specially sent from Queensland, also a Moreton Bay Chesnut, have been planted here. Vanity on my part, as I was born on the shore of Moreton Bay. The trees and shrubs and cannas are growing well and when the Opening Ceremony takes place, the "Grotto" will add beauty to the Approaches.

From the roadway intersection at Alfred Street, the roadway sunken between the two railway viaducts rises on a grade of 1 in 39 and is the same width as on the steel bridge, viz., 57 feet between kerbs. The roadway separates the pairs of

tracks/

tracks at Milson's Point Station and it was necessary to connect the platforms by a concourse underneath the roadway.

The concourse of Milson's Point Station extends below the construction, the central portion beneath the roadway widening out for the layout of the various station offices. Beyond the concourse barriers, stairways provide access to the platforms. There will be two entrances to the station, one from Alfred Street and one from Broughton Street. The former will be suitably featured in the face of the retaining wall fronting Alfred Street and will be finished with terra cotta facing and a decorative awning.

The concourse and stairways of Milson's Point Station are tiled to a height of about 6 feet. The groundwork, ivory-coloured tiles suitably ornamented by bands of henna tiling.

On both sides of the Broughton Street entrance there are display windows and shops. The viaduct from the 220 feet of steel arch to Burton Street is constructed of steel beams encased in concrete suitably waterproofed on concrete piers. The areas under this viaduct which front a new concrete road, the extension of Broughton Street, will be let for shops. The southern end of Milson's Point Station is built over the

Burton Street arch. This arch is a filled spandrel arch of 60 feet span containing 2,014 cubic yards of concrete and was poured in October, 1928, in eight days.

Fitzroy Street arch at the North End of Contract is 66 feet span and contains 2,122 cubic yards of concrete. It was poured in June, 1928, in nine working days.

Beneath the steelwork of the five steel approach spans is an area of about 10¾ acres which has been cleaned up, and which is to be converted into a park. The area includes part of the land resumed from the Sydney Ferries and Langdons Timber Yard. Along the southern boundary fronting the foreshores and passing in front of the northern abutment tower, a roadway has been laid out.

For the Northern Approach, a total of 469 properties were resumed and demolished; the properties including the Sydney Ferries Arcade, the station at Milson's Point, the Milson's Point Hotel and a number of shops.

The roadway of the Northern Approach consists of a reinforced concrete slab 8 inches in thickness on which is placed 3 inches of sheet asphalt laid in two courses each of 1½ inches. The asphalt cement used is Trinidad Lake asphalt which comes from the Island of Trinidad, discovered by

Columbus/

Columbus in 1498. Sir Walter Raleigh was the first Britisher to use it, caulking his ships there. The asphalt occurs as an asphalt lake from which it is excavated, refined and exported.

The electric current for lighting the roadway is brought across the Bridge from Argyle Substation and on the eastern side of the roadway there will be a row of fifteen ornamental lanterns spaced at about 90 feet intervals, each lantern has fifteen 60-watt lamps and provides excellent illumination for the sunken roadway which can only be lighted from one side.

The construction of the Northern Approach has involved an enormous amount of work and an expenditure for construction of one million pounds (£1,000,000), exclusive of the tunnels. The foundations for piers and abutments, regrading, etc., have necessitated 165,000 cubic yards of earth and rock excavation. For the tunnels, between Bank Street and Miller Street, 16,600 cubic yards of concrete were placed To build the concrete arches, retaining walls, piers, etc., 105,000 cubic yards of concrete have been poured.

In addition to the enormous amount of work involved in the excavation and placing of the concrete mentioned above,

there has been a considerable quantity of work such as steelwork, brickwork, waterproofing, roadwork, track-laying, installation of electrical and signalling equipment and a costly and by no means unimportant feature, the deviation and alterations of existing services such as water mains, sewers, telephone cables, electric light and power cables.

Next week I will describe the Southern Approach.

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No. 14.

199

THE SYDNEY HARBOUR BRIDGE.

Southern Approach Construction.

Last week I described the Northern Approach from Waverton to the North End of Dorman, Long's Contract and now I will tell you something about the Southern Approaches to the Bridge now being constructed by me from the South End of Dorman, Long's Contract, that is, at the end of the steel approach spans over George Street North, to Wynyard Station. Throughout the 3,700 feet of Dorman, Long's Contract, the roadway, railway and tramway tracks and the footways are at the same level at any particular cross-section, but after leaving the south end of Contract the railway and tramway tracks and the footways commence to grade down more steeply than the roadway so that at Argyle Cut sufficient difference in level between the roadway and rail tracks can be developed to allow the two pairs of tracks to be located beneath the roadway. The four tracks, two for railway and two for tramway, run underground in pairs at the tunnel portals near Argyle Street and continue underground to Wynyard Square. The grade of the tracks of the Southern Approach was the maximum allowed, that is, 1 in 30 compensated for curvature which means that the grade would be 1 in 30 where the tracks

are/

are in a straight line but if curved the grade would be lessened corresponding with the amount of curvature.

The roadway after leaving the end of Contract continues 57 feet wide between the kerbs until Argyle Street is crossed by a reinforced concrete arch bridge. From Argyle Street southwards to near Grosvenor Street it is an 80 feet roadway flanked by a 16 feet footpath on each side -- a wonderful highway 112 feet wide. From Argyle Street to Grosvenor Street the roadway grade is 1 in 30.

From the south end of Contract, to Argyle Street, the railway and tramway tracks, the roadway and the footways are carried on a two level embankment, the central and higher part of the embankment is occupied by the 57 feet roadway which is retained between concrete retaining walls supported on concrete piers spaced about 25 feet apart, these piers being carried down through the filling and founded on solid rock. The elevated roadway is flanked on each side by a pair of tracks and a footway at a lower level, the tramway tracks being on the eastern side and the railway tracks on the western side.

The lower embankments are retained between concrete retaining walls, the overall width being about 150 feet. At the end of Contract the roadway and footways and railway

tracks are carried by an arch viaduct of 300 semi-circular arches of 70 feet, 64 feet and 57 feet. Over Argyle Cut the whole construction which is 165 feet wide is carried by a reinforced concrete arch of 66 feet clear span. The roadway embankment which is 23 feet above the levels of the railway tracks at this point is retained by reinforced concrete retaining walls built to act integrally with the arch ring. The old stone arch over Argyle Cut built about 1860 was very useful in the construction of the new concrete arch bridge. Upon this old bridge the timber falsework was supported. The falsework which could not be carried on the old bridge was supported on large broad flange beams 34 inches deep placed across the Cut well above the limit of the top of any loaded vehicles. By this means Argyle Cut was maintained open for traffic during the whole of the construction of the Bridge with the exception of the two days when the old stone bridge was blown down. The widening of the Cut is now complete, a 40 feet roadway and two 10 feet footpaths being provided, 60 feet wide overall.

The footways after crossing the Bridge follow approximately the same grade as the railway tracks to Argyle Street and at the tunnel portals on each side ornamental stairways have been built. By means of these stairways anyone

crossing/

crossing the Bridge on the York Street North side can go down to York Street North, to the Bridge Highway or by means of a subway and cross under the railway tracks to Upper Fort Street. Similar facilities are provided on the Upper Fort Street, the western side. On account of the prominent positions of these stairways, it was necessary that they should be made features constructed to harmonise with the tunnel portals and the Argyle Street arch. The landings at the top of the stairways have been enlarged into a balcony from which extensive views of the Harbour and City may be obtained.

To mark the commencement of the 16 feet footpaths at the top of the Bridge Stairs, there are two lantern standards of a novel design. On account of the position, the wide expanse of the roadway, and the open spaces in the vicinity, the Ceremony of the Opening of the Bridge will take place here. Between these two lantern standards the ribbon will be cut at the Opening Ceremony of the Bridge on 19th March, 1932. From this pair of lanterns sapphire sheened by night, to the corresponding pair on the northern side near Milson's Point Station, gleaming topaz by night -- blue and gold, the University colours -- is a distance of 75 chains.

The Bridge Avenue will be connected to York, Clarence and Kent Streets near Grosvenor Street by the Crescent and

two/

two parklets. The two parklets, simple and beautiful, will afford clear vision and so render it safe for traffic converging at the Bridgehead. The two parklets have a total area of about 1 acre.

From Argyle Street to the Crescent the four tracks are almost entirely under the roadway. Where the roofs of the tunnels are in the residue areas which will be available for sale on the completion of the work, the steelwork of the roofs is designed to carry a load of 5 tons per sq. ft. which will allow a building 150 feet high to be constructed anywhere above the tunnels.

After passing under Grosvenor Street, the four tracks continue on under York Street North and the two single track tunnels of each pair merge together to form a double track tunnel so that in York Street parallel to St. Philip's Church grounds there are two double track tunnels beneath the roadway. The object of doing this was to make provision for crossovers between the two tracks of each pair and thus allow trains through from Central to be terminated at Wynyard Station if desired. At Jamieson Street the double track tunnels are bifurcated in a similar manner to those approaching North Sydney Station and with the same object to serve the two sides of each of the two island platforms. Construction was

first/

first commenced on the Southern Approaches in York Street between Jamieson Street and Grosvenor Street in September, 1926, where the four tracks were constructed by cut and cover One side of the excavation was adjacent to the wall of St. Philip's Church and great care had to be taken to avoid damage to the Church by blasting. Shortly afterwards, old Scots' Church was resumed and demolished to allow the tracks into Wynyard Station to be constructed. This Church, a well known landmark was over 100 years old when demolished, and it could not have remained in use much longer with safety. The walls were built of rubble stone and spalls with lime mortar, but the lime was sparsely used and the mortar had deteriorated, while being demolished the front portion and tower collapsed, fortunately without anyone being hurt. Less than an hour previously there had been large crowds in the vicinity to witness the Duke of York attending a function at the Wentworth Hotel. The new Scots' Church has now been completed; the design allows for additional stories to be added in the future to reach to the building limit of 150 feet.

Two of the single track tunnels pass under the new Scots' Church and some of the columns rest on top of the roof of the tunnels. Many of the columns transmit the enormous loads of

over/

over 1,000 tons to the steelwork roof of the tunnel.

To widen York Street between Grosvenor Street and Margaret Street to a width of 81 feet, a small strip was resumed from St. Philip's Church and portion of the old school room demolished. The roadway between Grosvenor Street and Margaret Street has been completed and opened for traffic.

In the design of the layout of the crescent and the junction with the existing streets, it was considered imperative to improve the grade of the old streets which lead from Kent Street. It thus became necessary to regrade Kent Street raising it by about 7 feet in the vicinity of Crescent Street which street has now disappeared. Being only 60 feet wide between kerbs, it was necessary to widen Kent Street to 81 feet as far as Napoleon Street where traffic can then turn into Hickson Road. Accordingly, Kent Street has been widened between Gas Lane and Napoleon Street. Some very old properties have been demolished while three large buildings each have had 21 feet cut off and new fronts built on the new alignment. Gas Lane, a very steep lane, gives access to a stairway serving Hickson Road, whilst Jenkins Street has been re-located northwards, Gas Lane and Jenkins Street reconstructed and their grades improved. Gas Lane paved in places with cobble-stones was a very old street, probably one of the

first/

first constructed. The two parklets have an area of about an acre, trees and shrubs have been planted there as a background, silky oaks bearing red and honey-coloured flowers and a beautiful foliage, red bottle-brushes, small-leaved figs and Moreton Bay Ash. These parklets have been turfed and will be carpets of grass on the Opening Day. In each parklet there is an ornamental lantern on a concrete shaft flanked by two drinking fountains.

On account of the proximity of the Fort Street Girls' High School and the risk to pedestrians crossing the Bridge Highway, a system of pedestrian subways has been constructed at the Crescent. There is a main subway 15 feet wide under the roadway and branching off from it are two 12 feet subways, leading to the footpaths in front of the two respective parklets. These subways are constructed of concrete roofed with steel beams encased in concrete, and are tiled to a height of 6 feet with white tiles suitably ornamented with bands of maroon tiles. These are the colours of the Girls' High School. The roadway of the Bridge Highway as constructed is an 8-inch slab of reinforced concrete surfaced with 3 inches of sheet asphalt. The sheet asphalt was put down in two courses each 1½ inches thick and is similar to that on the Northern Approach with the exception of the asphaltic cement.

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The bitumen used is an oil residual bitumen a by-product of the oil refineries of the United States of America.

For the Southern Approaches a total of 330 properties have been demolished. Included in this number is old Scots' Church, and five hotels, viz., the "Grosvenor", "Three Crowns", "Grand", "Flagstaff" and the "Manchester". Most of the properties were very old, some being over 100 years. In the early days of the settlement the area was the select residential area of Sydney and the Officers of the garrison regiments dwelt here. But as Sydney expanded, the area fell into disrepute and was practically all resumed in 1901 by the Government of the day when bubonic plague broke out, it was then the good intention to demolish the properties and remodel the area. The road to Hades is said to be paved with good intentions, the remodelling of this area is one of the paving-stones; the area grew slummier and slummier, and when it was demolished for the Bridge, in some of the buildings, on account of the insects there, additional money had to be paid to the demolishers, so I am told. One old building close to Fort Street School was the home of Sir George Reid when a boy. It had a wooden picket fence in front, on which, when he attempted to sit as a boy, he probably learned to say, "Yes-No". It is hard to sit comfortably on a picket fence.

Politicians then used to decry each other in poetry. Parkes and Reid had parted company for some reason or other in the 'eighties and at a subsequent election, Reid's voice was drowned by singing, maybe --

"Then rally and follow the leader,
The man of the lionlike breed,
Away with the vile seceder,
And down with the renegade Reid."

If we undergraduates hadn't a vote we had lungs and could make a noise, even if it were not singing.

One of the comparatively incidental, but yet very important parts of the construction of the Southern Approach was the design of the system of stormwater drainage. The major portion of the stormwater being piped through 24-inch monier pipes to Darling Harbour.

The following will convey an idea of the great amount of work performed in constructing the Southern Approach.

The excavation for foundations, cut and cover construction, and the regrading and widening of streets, etc., totalled 240,000 cubic yards of earth and rock excavation. Practically all this has been placed in permanent positions for embankments and as filling over cut and cover construction, etc., and the balance was dumped near Glebe Island to assist the Harbour Trust in reclaiming portion of Johnston's Bay.

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In constructing the tunnels in front of Petty's Hotel, there were 15,500 cubic yards of material excavated. This was a most difficult piece of tunnelling on account of York Street being just over the top of the tunnel, the upper portion of which was in shale and necessitated heavy timbering. As a consequence, the cost per cubic yard was approximately 27/-, which is 5/- more per cubic yard than the cost of the tunnelling at North Sydney, where the rock was good and tunnelling was not required.

Altogether 110,000 cubic yards of concrete have been mixed and placed in position, the major portion being in the cut and cover construction of the four railway tracks under the Bridge Highway. More than 3,000 tons of steelwork were used in roofing the tunnels.

Near Argyle Street, upon a residue area, the Railway Department has constructed the Argyle Substation. The electric current will be taken in at the substation at 6,000 volts, 25 cycles, 3-phase and transformed down to 1,125 volts, 25 cycles, 3-phase and it is then put through the rotary converters and will be distributed as direct current at 1,500 volts to drive the electric trains across the Bridge and the Quay section of the City Railway. Three rotary converters, each of 4,500 kW capacity have been installed and provision is made so that a fourth can be added. For the lighting of

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the Bridge roadway and footways, power is taken from Ultimo at 2,000 volts, 50 cycles, 3-phase and transformed down to 240 volts, 50 cycles, 3-phase.

The Main Arch Bridge will be illuminated by bracket type lamps at each cantilever bracket. It is proposed to instal 300-watt lamps on the roadway side and 200-watt lamps on the footway side. The lamps will have suitable refractor units to distribute the light on the roadway and footways. On the steel approach spans the lamps are spaced at about 90 feet intervals, the roadway lamps will be 500-watt and the footway lamps 300-watt.

To illuminate the Bridge Highway from Argyle Street to the Crescent connecting York, Clarence and Kent Streets, there will be a post type of lantern on top of precast reinforced concrete lamp standards, the rating of each lamp being 500-watts.

During the construction of the Approaches on both sides of the Harbour, we have used over 100 tons of explosives; I am thankful to say without a single accident, although the children at North Sydney, notwithstanding all attempts to stop them, would rush to catch the small pieces of rock which escaped from the covering rope mattresses as they fell. Of this quantity, gelatine dynamite comprised 30 tons and lithyte 30 tons.

The/

The old Dawes' Point Park will be considerably improved and increased in area. When commencing the work in 1924, the old Water Police Station and the old de-licensed "Harbour View" Hotel were demolished and recently the buildings at one time used by the Repartriation Department and then by Dorman, Long and Company, for their offices, have shared the same fate.

Dawes' Point has many historical associations. The first Observatory was established there by Lieutenant Dawes to observe a comet which could be favourably seen in the Southern Hemisphere. Later, the same Lieutenant Dawes built a battery here to defend Sydney, and the area became known as Dawes' Point.

The area has now been regraded and when completed, the park will have an area of about 5½ acres and will form a fitting setting for the Southern Abutment Tower and Pylon of the Bridge.

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No. 15.

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THE SYDNEY HARBOUR BRIDGE.

Broadcast 21st February, 1932.

Good evening, Australia! In the fifteen minutes at my disposal, I will tell you a little about Sydney's Great Bridge, to be opened for traffic on March 19th, next.

About 20 years ago, I was appointed Chief Engineer, Sydney Harbour Bridge & City Transit, to bring to fruition my creations, the Bridge and City Railway. These should be a real link in the transportation facilities of the Commonwealth, for when the railway gauges are unified, the Transcontinental Express can start at, say, Rockhampton on its 4,000 mile run to Fremantle, via the Bridge and City Railway, which have been designed to carry such traffic.

As authorised by the Enabling Act, the Sydney Harbour Bridge consists of an arch bridge across Sydney Harbour from Dawes' Point to Milson's Point, and the railway and roadway approaches thereto, the railway connecting with the City Railway at Wynyard Station and with the Milson's Point to Hornsby Line at Waverton Station, a total length of 2 miles 43 chains.

The main arch and steel approach spans, a length of 3,770 feet, have been constructed under Contract by Dorman, Long & Company, Limited, of Middlesbrough, England, the Approaches,

1 mile/

1 mile 66 chains in length, have been constructed under me by day labour. The Bridge provides for four lines of electric railway traffic, for a roadway 57 feet wide in the clear between kerbs, and for two footways each 10 feet wide; the headway for shipping at mean high water is 170 feet. On the Opening Day, 72 trains, 120 trams, 3,000 vehicles to and 3,000 vehicles from the City and 20,000 foot passengers could traverse it in any hour.

The salient features of the Northern Approaches are the tunnels under the Church of England Grammar School Hill, the North Sydney and Milson's Point Stations, the series of arch bridges carrying the railway and tramway tracks over the streets below, the shopping facilities provided under the viaducts and at the railway stations, which should return sufficient rental to pay interest on at least £250,000, also the Highway for the vehicular traffic.

Trains from the Milson's Point to Hornsby railway will traverse the Bridge on the western pair of tracks and the tramways of North Sydney will be brought into the City on the eastern pair of tracks, until these are required for railway purposes.

The Main Bridge consists of a steel arch span, 1,650 feet centres of bearing pins, flanked on either side by the

abutment/

abutment towers and pylons, also five steel approach spans on either shore, a total length of 3,770 feet, and weight of steel 52,781 tons.

The granite-faced abutment towers and pylons are the architectural features of the Bridge and harmonise with the lines of the arch. The pylon parapets are 285 feet, and the pylon tops 291.5 feet high above mean sea level. A stairway rises from ground level to deck level, and provision has also been made for a lift, if found necessary. A cross-footway under the main deck connects the Bridge footways at each pylon, and stairways give access to the top of each pylon.

The four main bearings supporting the arch spans each weigh 296 tons, and comprise steel castings and forgings, individual pieces weighing up to 33 tons. The thrust on each bearing 44,100,000 is taken by a pin 14½ inches diameter, encircled by heavy steel forgings.

The two-hinged silicon steel arch trusses, 98 feet 6 inches apart centres, are set in vertical planes and have a span of 1,650 feet and a rise of 350 feet, i.e., the vertical height between the centres of pins in the main bearings and the centre of pins at the centre of the lower chords is 350 feet. The lower chord is parabolic in outline, the depth of the arch truss at the crown is 60 feet, the depth at the end post is

187 feet/

187 feet 9 inches. The summit of the arch is 440 feet above mean sea level. Each arch truss is divided into 28 panels with a single system of bracing, the arches are braced together by top and bottom laterals, with transverse frames at each end post. All members of the arch are 11 feet wide, but of shallow depth. The lower chord 48 inches at the crown, 99 inches at the bearings; the top chord 40 inches deep throughout, except the end panels, which were tapered to provide for the steel erection pins 27 inches in diameter, which are now removed. All main members are built of silicon steel, and the deck of carbon steel. The largest angle used is 12 inches by 12 inches by $1\frac{1}{4}$ inches, the thickest plate $2\frac{1}{8}$ inches and the largest rivet $1\frac{13}{32}$ inches diameter. Viewed from the deck, which is 160 feet wide on the arch span, the wilderness of steel beams is enthralling, a fairylike structure, a noble solidity in steel.

On the southern side, the approaches consist of three reinforced concrete arch spans of 70 feet, 64 feet and 57 feet respectively, leading firstly to rock-filled embankments enclosed between concrete retaining walls, and then a concrete arch bridge over Argyle Cut of 66 feet span. The rail tracks descend more rapidly than the roadway, and, passing over Argyle Cut, the four tracks converge and are situated under

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the roadway, where they proceed in tunnels to Wynyard Station.

On the south side of Argyle Cut, foot traffic from the Bridge will reach the existing footpaths by means of the ornamental stairways at York Street North and Upper Fort Street, which streets are here inter-connected by a subway between these stairways. From Argyle Cut, Citywards, the Bridge Highway, 80 feet wide to provide for six lanes of through and two lanes of standing traffic, and two footpaths each 16 feet wide, will be flanked with buildings. The roofs of the subways are designed to carry a load of 5 tons per sq. ft., so as to allow buildings up to 150 feet in height to be built in any position above the subways. At the City Bridgehead, two parklets planted with Australian trees give uninterrupted vision for motor traffic, whilst subways from York, Clarence and Kent Streets are provided for foot passengers to and from the footpaths of the Bridge Highway.

The special feature in the lighting of the Bridge and Approaches is the elimination of glare, the lantern fittings direct the major portion of the light downward for the effective lighting of the roadway and footways, but allow a small amount of diffused light to penetrate upwards and outwards; otherwise there would be a well-lighted area below the lanterns to the deck, with a dark canopy above.

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For the fabrication of the Bridge, there were two shops, a light shop in which steel members up to 50 tons were fabricated, and the heavy shop where members up to 122 tons were completed. These shops were equipped with the most modern machinery and enabled the high standard of work as required by me to be reached. Where chords of the arches butted, if a steel feeler 4/1,000th of an inch could be inserted between the pieces being fitted, the work was not passed until this perfection had been obtained. The shop plan length of each top chord between centres of end verticals was 1,723 feet $2^{3}/16$ inches, the actual length of the eastern truss was $^{1}/16$ inch longer than that figure, and the western truss $^{1}/4$ inch shorter. Similarly, the shop length of the bottom chord was 1,830 feet $8^{3}/4$ inches, the finished length of the eastern arch was $^{3}/32$ inch short and of the western truss $^{1}/32$ inch short, showing the perfection of the work; out of $5\frac{1}{2}$ million rivets, only some 101,559 were replaced during fabrication and erection. A higher standard of perfection has not been attained in any bridge. The rivets in the main chords were longer than in any other bridge yet erected anywhere, the grip of the rivets, i.e., the length between the rivet heads was 12 inches. To ensure that the rivets would completely fill the holes, the rivets were made with a taper, and were $^{1}/32$ of an inch less in diameter than the diameter of the rivet hole.

After/

After heating to a red heat, the end of the rivet was cooled to a black red heat, so that the rivet under pressure would stave up and fill the hole before the head was formed.

A further indication of the perfection of the work is revealed by the test loading. The central 1,100 feet of Bridge on each of the four tracks has been loaded with locomotives weighing nearly 2,000 tons per track and the greatest difference of deflection which has been measured of one arch with the other is 1/16th of an inch.

The Contractors' erection scheme was based on the method carried out by Monsieur Georges Imbault for the erection of the Victoria Bridge across the Zambesi River, M. Imbault was Consulting Engineer to the Contractors when they tendered. The erection scheme consisted in supporting each half-arch, weighing 13,670 tons, by means of 128 cables, which cables passed through tunnels 120 feet deep cut in solid sandstone and against which rock the cables bore. Each cable, 1,200 ft. long by 2 3/4 inches diameter, consisted of 217 wires and weighed 8½ tons. The minimum breaking strength per cable was 360 tons, the maximum load they carried just prior to closing was 107.5 tons. The cables in eight rows of sixteen cables were connected by means of 11-inch steel pins and a system of bolts and washers to fan-shaped steel links, which

links/

links were connected to the top chords by special chromium steel pins 27 inches in diameter. The total pull on each system of cables was 27,440 tons and the thrust on each of the four main bearings 17,660 tons. The special bolts had long threaded ends with special nuts, each pair was connected by steel forgings, and by means of hydraulic jacks, seated on the forgings, the pressure on the nuts could be released, hence by moving the nuts up or down on the bolt, the length of the cable system would be increased or decreased when the jack was removed. The members of the arches were erected by creeper cranes, each crane weighed 606 tons and could lift members weighing 120 tons. The arch was erected, panel by panel, until 13½ panels were complete. By manipulating the jacks, the cable systems were lengthened and the half-arches lowered until they met at the centre of the bottom chord. The ends of the centre panels of each chord were fitted with two heavy steel forgings each recessed to enclose a steel pin 8 inches in diameter. These 8-inch pins were set-screwed into the forgings on one side, so that when lowered, the other forging would fit on the pin. To ensure the chords could be brought into line and level, a steel locking bolt, 10 inches square was fitted in one chord, and, by means of an hydraulic jack, the bolt was forced forward into a diaphragm 10 inches square fitted on the other

chord. The end of the locking bolt was tapered, so that when the small end entered the diaphragm and the bolt was pushed forward, the chords would be drawn into line and level. The arch closed on August 19th, 1930, at 10 p.m. The centre half-panels were then erected, the ends of the top chords fitted with steel forgings enclosing a pin 9 inches diameter, the upper chords of each half-arch were jacked apart with a pressure of 3,250 tons, and steel packings were inserted behind the forgings to fill the space of 5 1/4 inches caused by the jacking. This jacking put the backbone into each arch, and was completed on September 10th, 1930. From the time the lower chords met until the upper chords were jacked apart, the arch rose 13½ inches, the weight of each arch was 14,000 tons.

The Bridge will make it possible for upwards of a million people to reside in the northern suburbs and when I visualise the future, I feel that I was born some 30 years too soon, because the achievement of today will be but a stepping-stone for greater engineering feats, a bridge across the Heads maybe, and other traffic facilities necessary for the development of this great City, one day to be the Queen City of the Empire.

Under the direction of Mr. Ennis, the arch grew, panel by panel, until it became the thing of beauty it is. Great credit must be given to him and his staff for accomplishing

what was freely said to be impossible.

I desire to thank my own staff, who assisted me in checking all the calculations and plans for the main structure, under the terms of the Contract these had to be forwarded by the Contractors for my check and approval before any work could be undertaken by the Company; to my staff I tender my thanks also for their assistance in the checking and supervision of the Contract and for the design and the construction of the Approaches, and in tendering my thanks, I do not forget the workmen who so splendidly responded to the trust reposed in them. Throughout they worked magnificently, and built the Bridge, a credit to Industrial Australia.

May Sydney's Bridge inspire Australia's children to express in their lives and their work that spirit of co-operation and service so necessary for Australia's welfare, and using to the full the heritage from our glorious Empire, may they strive to excel in all that is noblest and best.

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No. 16.

SYDNEY HARBOUR BRIDGE OFFICIAL OPENING.

Broadcast Speech by Dr. J. J. C. Bradfield,
Saturday, 19th March, 1932.

Your Excellency, Mr. Premier, My Lord Mayor, Ladies and Gentlemen:

I desire to express my sincere thanks for the generous appreciation of the work in which the Contractors, my Staff and myself have shared, and for the compliment paid me in naming the link with north and south the "Bradfield Highway".

The Bridge will make it possible for upwards of a million people to reside in the Northern Suburbs and when I visualise the future, I feel that I was born some thirty years too soon, because the achievement today will be but a stepping-stone for greater Engineering feats, a Bridge across the Heads maybe, and other traffic facilities necessary for the development of this great City, one day to be the Queen City of the Empire.

Under the direction of Mr. Ennis, the arch grew, panel by panel, until it became the thing of beauty it is. Great credit must be given to him and his Staff for accomplishing what was freely said to be impossible.

To my own Staff, who assisted me in the supervision of

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the Contract and the construction of the Approaches, I tender my grateful thanks for their loyal help and unselfish co-operation, and in tendering my thanks, I do not forget the workmen who so splendidly responded to the trust reposed in them. Throughout they worked magnificently, and built the Bridge, a credit to Industrial Australia.

My wife and children freed me from home cares and for the past twenty years the aim of my life has been to bring to fruition the function of today.

There is something within the hearts and minds of any people which kindles with pride at some great national achievement, and Sydney's Bridge is I think something to be proud of. May it inspire Australia's children to express in their lives and their work that spirit of co-operation and service so necessary for Australia's welfare, and using to the full the heritage from our glorious Empire, strive to excel in all that is noblest and best.

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